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THE

PHYSIOLOGY OF MAN;

DESIGNED TO REPRESENT

THE EXISTING STATE OF PHYSIOLOGICAL SCIENCE,

AS APPLIED

TO THE FUNCTIONS OF THE HUMAN BODY.

BY

AUSTIN FLINT, Jr., M.D.,

PROFESSOR OF PHYSIOLOGY AND PHYSIOLOGICAL ANATOMY IN THE BELLEVUE HOSPITAL MEDICAL COLLEGE, NEW YORK; ATTENDING PHYSICIAN TO THE BELLEVUE HOSPITAL; CONSULTING PHYSICIAN FOR THE CLASS OF NERVOUS DISEASES TO THE BUREAU OF MEDICAL AND SURGICAL RELIEF FOR OUT-DOOR POOR, BELLEVUE HOSPITAL; FELLOW OF THE NEW YORK ACADEMY OF MEDICINE; MEMBER OF THE MEDICAL SOCIETY OF THE COUNTY OF NEW YORK, ETC., ETC.

ALIMENTATION; DIGESTION; ABSORPTION; LYMPH AND CHYLE.

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1873.

PREFACE.

In the preface to the first part of this work, published a little more than a year ago, the author announced his intention of writing an extended treatise upon human physiology; and the present volume, devoted to subjects connected with the great functions of digestion and absorption, is now presented, as the second of the series. As stated in the preface to the first volume, the separate parts of the work are intended to form distinct treatises, devoted respectively to natural subdivisions of the science of physiology; each one being complete in itself, but the entire series embracing all the subjects usually regarded as belonging to human physiology. The manner in which the first part has been received, and the experience of the author in the preparation of the present volume, have encouraged him in carrying out the original plan of the work. To give to every subdivision of physiology that careful reflection and critical study, which alone could enable one to form a calm and dispassionate judgment upon the difficult questions which are constantly arising, involves an amount of time and patient labor which might well discourage the most enthusiastic student. A work of such magnitude, however

can be accomplished much more efficiently, by dividing it into separate and distinct parts. By publishing each part separately, the whole subject of human physiology, great as it is, may be considered with a degree of elaborateness which is generally looked for only in special treatises. This does not necessarily involve great voluminousness; on the contrary, it frequently happens that subjects, the literature of which is excessively abundant, may be considered, from a practical and positive point of view, in a comparatively small space, ignoring nothing that is valuable, and taking pains only to compare and harmonize conflicting experiments and observations. A practical acquaintance with experimental methods of observation frequently enables the physiologist to accomplish this end, and thus relieve certain complicated questions of much of their obscurity.

The subjects taken up in the present volume form a subdivision of physiology of the greatest importance and interest, to the general as well as to the professional reader. The first of these, alimentation, does not always receive sufficiently extended consideration in works upon physiology; though it is evident that the properties and physiological relations of matters which are destined to become part of the living body can hardly be studied too closely. The effects of improper and insufficient alimentation, also, which are too often observed in the poorer classes, particularly in large cities, are of the highest importance. The author, through the kindness of Dr. W. H. Van Buren, of the United States Sanitary Commission, has been enabled to present some important physiological facts connected with the celebrated Andersonville prison, noted on the spot by Prof. Joseph Jones, M. D., formerly of Georgia,

who was appointed during the late war by the medical authorities at Richmond to report upon the condition of the prisoners confined in the stockade. Such an opportunity for observing the effects of improper and insufficient alimentation upon large bodies of men has never been presented before, and probably will never occur again.

In studying the subject of digestion, many points presented themselves which were complicated by a mass of conflicting observations and statements by the earlier physiologists, and even by modern experimenters; and there are, even now, serious differences of opinion with regard to some of the most important facts connected with this function. This is strikingly illustrated in the views of different writers of high authority concerning the physiological properties of the saliva, the gastric juice, the bile, and the secretion of the pancreas. Much of this confusion is to be avoided, however, by treating of these questions upon the basis of accumulated experimental facts, without regarding mere opinions, even of the highest authority, when based upon insufficient data.

With regard to absorption, very much has been developed within the last few years by accurate experimental researches, in which some of the sources of error in the earlier observations have been avoided, by remarkably successful experiments upon living animals, and by the application of improved methods for the analysis of the animal fluids. Recognizing the importance of all these methods of study, the author has endeavored to give the most extended application of physical laws to the mechanism of absorption, without losing sight of the fact that the physical phenomena presented in the living body are by no means fully understood.

Our positive knowledge concerning many of the functions considered in the present volume dates from important discoveries. The author has in all cases made it his duty to trace these discoveries to their original sources; but in his historical researches, he has often found that the reputed authors of important original observations had, generally without their knowledge, been anticipated. The only object in making references to the works of the earlier physiologists has been to do justice, as far as possible, to every original observer; and all the works cited in foot-notes have, without exception, been consulted by the author personally, in the original, and the references clearly indicated.

Most of the important facts connected with the functions of digestion and absorption have been repeatedly verified by the author in his laboratory and in public demonstrations; and in many instances, the observations of others have been more or less extended. The most important original observations, however, are upon the excretion of cholesterine in the bile, and its transformation into stercorine in its passage through the intestinal canal. In the present volume, this question is considered in connection with the digestive function of the bile and the composition of the fæces. It will be considered much more elaborately, under the head of Excretion, in another volume.

The succeeding volumes of the series will be devoted to Secretion and Excretion, Nutrition, Movements, etc., the Nervous System, and Generation. They will appear as rapidly as is consistent with their careful preparation.

NEW YORK, June, 1867.

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PHYSIOLOGY OF MAN.

CHAPTER I.

HUNGER, THIRST, AND INANITION.

General considerations—Appetite—Circumstances which modify the appetite—Influence of climate and temperature—Influence of exercise and occupation—Influence of habit—Influence of alcohol, tobacco, etc.—Influence of extirpation of the spleen or of one kidney—Hunger—Location of the sense of hunger—Thirst—Location of the sense of thirst—Inanition—Loss of weight in inanition—Effects of inanition on circulation, respiration, animal temperature, and the nervous system—Duration of life in inanition—Insufficient alimentation.

THE power of self-regeneration is one of the great distinctive properties belonging to all organized living bodies. In the organism of animals, every part is continually undergoing what may be called physiological decay; the organic nitrogenized principles are being constantly transformed into effete matter; and as these principles never exist without inorganic principles, with which they are closely and inseparably united, it is found that the products of their decay are always discharged from the body in combination with inorganic matters. This process of molecular change is a necessary and inevitable condition of life. Its activity may be increased or retarded by various means, but it cannot be arrested. The excrementitious principles which are thus formed are produced constantly by the tissues, and must be continually removed from the organism, otherwise they

accumulate and induce serious toxic conditions. Examples of this are found in those diseases of the kidneys which interfere with the elimination of urea, producing uræmic poisoning, and in diseases of the liver which interfere with the elimination of cholesterine, giving rise to cholesteræmia.

It is evident from the amount of matter which is daily discharged from the body that the process of destructive assimilation, as it is sometimes called, must be very active. Its constant operation necessitates a constant appropriation of new matter by the parts, in order that they may maintain their integrity of composition, and be always ready to perform their functions in the economy. The blood contains all the principles necessary for the regeneration of the organism. Its inorganic constituents are generally found in the same form in which they exist in the substance of the tissues; but the organic principles of the parts are formed in the substance of the tissues themselves by a transformation of material furnished by the blood. The physiological decay of the organism is, therefore, being constantly repaired by the blood; but in order to keep the great nutritive fluid from becoming impoverished, the materials which it is constantly losing must be supplied from some source out of the body, and this necessitates the ingestion of matters which are known as food. Food is taken into the body in obedience to a want on the part of the system which is expressed by the sensation of hunger, when it relates to solid or semi-solid matters, and thirst, when it relates to water. As these sensations are the first cause of the introduction of the materials capable of regenerating the blood, their consideration naturally precedes the study of digestion, the process by which the articles of food are prepared for absorption and appropriation by the circulating fluid.

Hunger and Thirst.

The term hunger may be applied to all degrees of that peculiar want felt by the system which induces the ingestion

of nutritive principles. Its first manifestations are, perhaps, best expressed by the term appetite; a sensation by no means disagreeable, and one which may be excited by the sight, smell, or even the recollection of savory articles, at times when it does not absolutely depend on a want in the system. In the ordinary and moderate development of the appetite, it is impossible to say that the sensation is located in any distinct part or organ. It is influenced in some degree by habit; in many persons, the feeling being experienced at or near the hours when food is ordinarily taken. If not soon gratified, the appetite is rapidly intensified until it becomes actual hunger. Except when the quantity of food taken is unnecessarily large, the appetite simply disappears on the introduction of food into the stomach, and gives place to the sense of satisfaction which accompanies the undisturbed and normal action of the digestive organs; or, in those who are in the habit of engaging in absorbing occupations at that time, the only change experienced is the absence of desire for food. The sense of oppression and fulness which attends over-distension of the stomach is simply superadded to the feeling of satisfaction of the appetite, and is not a necessary part of it.

In man, the appetite is usually manifested in a marked degree at least twice, and generally three times, in the twenty-four hours. In this country, food is commonly taken three times daily. In childhood, when the system demands material, not only for the repair of worn-out parts, but for growth, food is generally taken oftener and in larger relative quantity than in the adult. The infant should satisfy the appetite at least six or seven times in the twenty-four hours; and nothing has a more serious influence upon the development of the growing child than bad quality or a restricted quantity of food.

It has been observed that children and old persons endure deprivation of food by no means so well as adults. This fact was noted by M. Savigny in the case of the wreck of the frigate Medusa. After the wreck, one hundred and fifty

persons, of all ages, were exposed on a raft for thirteen days with hardly any food. Out of this number only fifteen survived, among them M. Savigny, and the children, young persons, and the aged, were the first to succumb.[1]

Important modifications in the appetite are due to temperature. In cold climates, and during the winter season in all climates, the desire for food is notably increased, and the tastes are somewhat modified. Animal food, and particularly fats, are more agreeable at that time, and the quantity of nutriment which is demanded by the system is then considerably greater. In many persons, the difference in the appetite in warm and cold seasons is very marked, and they habitually lose flesh in the summer and regain it in the winter.

Exercise and occupation, both mental and physical, when not pushed to the point of exhaustion, increase the desire for food and undoubtedly facilitate digestion. Certain articles, especially the vegetable bitters, taken into the stomach immediately before the time when food is habitually taken, frequently have the same effect; while other articles, which do not satisfy the requirements of the system, have a tendency to diminish the desire for food. Many articles of the materia medica, especially preparations of opium, have, in some persons, a marked influence in diminishing the appetite. The abuse of alcoholic stimulants will sometimes take away all desire for food. When hunger is pressing, it has been observed that tobacco, in those who are accustomed to its use, will frequently allay the sensation for a time.[2] When the

[1] Savigny, *Observations sur les Effets de la Faim et de la Soif, éprouvées après le Naufrage de la Frégate du Roi, la Meduse, en* 1816. Thèse, No. 84, Paris, 1818.

[2] In this connection, the experience of Dr. W. A. Hammond, who was delayed for a number of hours on the railroad between Philadelphia and New York, is very instructive. On this occasion, Dr. Hammond was deprived of food for twenty-eight hours. During this time, when the sense of hunger became very intense, he obtained marked though temporary relief by smoking tobacco. This he repeated several times, always with the same result. (Verbal communication.)

system has been badly nourished from any cause, as after prolonged abstinence, or in recovery from an exhausting disease, hunger is generally pressing and almost constant; and this continues until the organism has regained its normal condition. Under these circumstances, the ingestion of food, even in unusually large quantity, has but a momentary effect in appeasing the appetite; showing that though the feeling of satiety which follows the introduction of a sufficient quantity of food into the stomach is experienced, the system still feels the want of nourishment, and this want is expressed by an almost immediate recurrence of the appetite.

In some of the lower animals, extirpation of the spleen has been observed to be followed by a marked increase in the appetite;[1] but this effect is by no means constant, and it sometimes follows removal of one kidney, an operation which does not appear to interfere with any of the physiological processes.

If food be not taken in obedience to the demands of the system as expressed by the appetite, the sensation of hunger becomes most distressing. It is then manifested by a peculiar and indescribable sensation in the stomach, which soon becomes developed into actual pain. This is generally accompanied by intense pain in the head and a feeling of general distress, which soon render the satisfaction of this imperative demand on the part of the system the absorbing

[1] The following observation showed a very remarkable increase in the appetite consequent upon the removal of the spleen.

Feb. 11, 1861. The spleen had been removed from a young dog, the subject of this operation, about six weeks before. The animal recovered from the operation without a bad symptom, and is perfectly well, sleek, and fat, weighing twenty-two pounds. Since the operation, the disposition has become ferocious, so that it is dangerous to come near him. The appetite is insatiable, and he will eat even the refuse from the dissecting-room.

The dog was brought before the class at the New Orleans School of Medicine at two P. M., and ate a little more than four pounds of beef-heart, or nearly one-fifth of his weight. He had been fed abundantly about twenty-four hours before.

idea of existence. Starvation overcomes, in many instances, every moral and intellectual feeling, and gives full play to the purely animal instincts. Furious delirium frequently supervenes after a few days of complete abstinence; and this is generally the immediate precursor of death. It is unnecessary to cite any of the numerous instances in which murder and cannibalism are resorted to when starvation is imminent; suffice it to say, that the extremity of hunger or of thirst, like the sense of impending suffocation, is a demand on the part of the system so imperative, that it must be satisfied if within the range of possibility. There have been instances of sublime resignation in the face of this terrible agony, but these are rare in comparison with the examples of frightful expedients to satisfy the demands of nature.

The question of the location of the sense of hunger is one of considerable physiological interest. When we say that it is instinctively located in the stomach, it is simply expressing the fact that the sensation is of a nature to demand the introduction of food into the alimentary canal. The sense of want of air demands the introduction of fresh air into the lungs; but, though air be inspired, if any thing interfere with its passage to the system by the blood, the demand for oxygen is unsatisfied. It has been shown that the real seat of the respiratory sense is in the general system, and that this is referred to the lungs because, necessarily, it is by the introduction of air into these organs that the want is met. This fact can be readily proven, as the effects of deprivation of oxygen are almost instantaneously manifested. It is easy to introduce air artificially into the lungs, and by simply interrupting the circulation, or by draining the system of blood, to prevent its access to the system. The same principle is manifested, in a manner no less distinct, with regard to the ingestion and assimilation of food. When the system is suffering from defective nutrition, as after prolonged abstinence or during recovery from diseases which have been accompanied by lack of assimilation, the mere filling

of the stomach produces a sensation of repletion of this organ, but the sense of hunger is not relieved; but if, on the other hand, the nutrition be active and sufficient, the stomach is frequently entirely empty for a considerable time without the development of the sense of hunger. The following observation bears strongly on this point: In a dog with a fistula into the gall-bladder, the bile-duct having been tied and partly exsected, digestion was so much interfered with that death from inanition took place in thirty-eight days; and although the animal took food abundantly, the appetite was voracious and never satisfied.[1] The same phenomenon has sometimes been observed in cases of diabetes accompanied with great deficiency of assimilation. The appetite is preserved and hunger is felt by persons who suffer from extensive organic disease of the stomach, and the sensation has been occasionally relieved by nutritious enemata or by injections into the veins.

An interesting and curious case has lately been reported by Prof. Busch, of Bonn, which points almost conclusively to want of assimilation of nutritive matter by the general system as the great cause of the sensation of hunger. In this case, which will be more fully detailed hereafter, there was a fistula into what appeared to be the upper third of the small intestine. The patient was a woman, thirty-one years of age, in the sixth month of her fourth pregnancy, and received the injury which resulted in the fistulous opening, by being tossed by a bull, one of the horns penetrating the abdomen. She was seen by Prof. Busch six weeks after the injury, at which time every thing taken into the stomach passed at the upper opening of the fistula. Although the patient took food in large quantity, she became extremely emaciated and weak. "The patient at first had a most voracious appetite; she never felt satisfied. She continued to eat, even when the first portions of food which she had taken

[1] See an article by the author, on a *New Excretory Function of the Liver.* —*American Journal of the Medical Sciences*, Oct., 1862.

were escaping through the opening. She would then say that she felt better, but was still hungry. Prof. Busch infers that hunger is composed of two separate sensations—one general, the other local; the former resulting from the want of material to supply the waste of tissue."[1]

These facts render it certain that the appetite and the sense of hunger are expressions of a general want on the part of the system, referred by our sensations to the stomach, but really located in the general system. This want can only be completely satisfied by the absorption of digested alimentary matter by the blood and its assimilation by the tissues. This is so evident, with our present knowledge, that it is unnecessary to discuss the various theories which have been proposed to account for the sense of hunger; such as repletion of the tubes of the stomach with gastric juice, the reflux of bile from the duodenum, rubbing together of the walls of the stomach, etc., etc.

The sense of hunger is undoubtedly appreciated by the cerebrum, and it has been a question whether there be any special nerves which have the function of conveying this impression to the great nervous centre. The nerve which would naturally be suspected to possess this function is the pneumogastric; but in spite of certain observations to the contrary, it has been proven that section of both of these nerves by no means abolishes the desire for food.[2] Longet has observed that dogs eat, apparently with satisfaction, after section of the glosso-pharyngeal and lingual nerves.[3] The last-named observer is of the opinion that the sensation of hunger is conveyed to the brain through the sympathetic system. Although there are various considerations which render

[1] Busch, *Beitrag zur Physiologie der Verdauungsorgane.*—Virchow's *Archiv*, 1858, S. 140 *et seq.* A summary of this case is also given in the *American Journal of the Medical Sciences*, July, 1860, p. 217, and in the *North American Medico-Chirurgical Review* of the same date.

[2] Leuret et Lassaigne, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 211.

[3] Longet, *Traité de Physiologie*, Paris, 1861, tome i., p. 20.

this somewhat probable, it is not apparent how it could be demonstrated experimentally. It is undoubtedly the sympathetic system of nerves which presides specially over nutrition; and hunger, which depends upon deficiency of nutrition, is certainly not conveyed to the brain by any of the cerebrospinal nerves.

Thirst is the special sensation which induces the ingestion of water. In its moderate development, this is usually an indefinite feeling, accompanied with more or less sense of dryness and heat of the throat and fauces, and sometimes, after the ingestion of a quantity of very dry food, by a peculiar sensation referred to the stomach. There is nothing agreeable connected with the sensation of thirst under any circumstances; but when it has become intense, the immediate satisfaction which follows the ingestion of a liquid, particularly water, is very great. Thirst is very much under the influence of habit, some persons only experiencing a desire to take liquids two or three times daily, while others do so much more frequently. The sensation is also sensibly influenced by the condition of the atmosphere, as regards moisture, by exercise, and other circumstances which influence the discharge of water from the body, particularly by the skin. A copious loss of blood is always followed by great thirst. This we have frequently noticed in the inferior animals. After an operation involving hemorrhage, they nearly always drink with avidity as soon as released. In diseases which are characterized by increased discharge of liquids, thirst is generally excessive.

The demand on the part of the system for water is much more imperative than for solids; in this respect being only second to the demand for oxygen. Animals will live much longer deprived of solid food, but allowed to drink freely, than if deprived of both food and drink.[1] A man, supplied

[1] It is a well-known fact that in inanition, the ingestion of water prolongs life, in man and in the mammalia; but the observations of Chossat have shown that

with dry food, but deprived of water, will not survive beyond a few days. Water is necessary to the function of nutrition, and acts, moreover, as a solvent in removing from the system the products of destructive assimilation.

After deprivation of water for a considerable time, the intense thirst becomes most agonizing. The dryness and heat of the throat and fauces are increased, and accompanied by a distressing sense of constriction. A general febrile condition supervenes, the blood is diminished in quantity and becomes thickened, the urine is scanty and scalding, and there seems to be a condition of the principal viscera approaching inflammation. Death takes place in a few days, generally preceded by delirium.

The sensation of thirst is instinctively referred to the mouth, throat, and fauces; but it is not necessarily appeased by the passage of water over these parts, and it may be effectually relieved by the introduction of water into the system by other channels, as by injecting it into the veins. Bernard has demonstrated by the following experiment that water must be absorbed before the demands of the system can be satisfied: He made an opening into the œsophagus of a horse, tied the lower portion, and allowed the animal to drink, after he had been deprived of water for a number of hours. The animal drank an immense quantity, but the water did not pass into the stomach, and the thirst was not relieved. He modified this experiment by causing dogs to drink with a fistulous opening into the stomach by which the water was immediately discharged. They continued to drink without being satisfied, until the fistula was closed and the water could be absorbed.[1] We have often repeated the latter experiment in public demonstrations. In

this does not take place in birds, in which starvation seems to take away the desire for drink (CHOSSAT, *Recherches Expérimentales sur l'Inanition*, Paris, 1843, p. 59).

[1] BERNARD, *Leçons de Physiologie Expérimentale, cours de semestre d'été*, Paris, 1856, p. 51.

one of these, particularly, the animal drank repeatedly until he had taken several quarts of water, only ceasing from fatigue, and soon recommencing; but as soon as the fistula was closed, he drank a moderate quantity and was satisfied.

In a case reported by Dr. Gairdner, of Edinburgh, in the human subject, all the liquids swallowed passed out at a wound in the neck by which the œsophagus was cut across. The thirst in this case was insatiable, though buckets-full of water were taken in the day; but on injecting water, mixed with a little spirit, into the stomach, the sensation was soon relieved.[1] This observation was made in 1820, long before the experiments just referred to upon the inferior animals.

Though the sensation of thirst is located in special parts, it is an expression of the want of fluids in the system, and is only to be effectually relieved by the absorption of fluids by the blood. There are no nerves belonging to the cerebro-spinal system which have the office of carrying this sensation to the brain, division of which will abolish the desire for liquids. Experiments show that no effectual relief of the sensation is afforded by simply moistening the parts to which the heat and dryness are referred. As a demand on the part of the system, it is entirely analogous to the sense of want of air and of hunger, only differing in the way in which it is manifested.

Inanition and Insufficient Alimentation.

The history of inanition belongs more to pathology than to physiology. To make use of the striking and oft-repeated quotation from the admirable monograph of Chossat, it is "a cause of death which advances in the front and in silence in every disease in which alimentation is not in a

[1] GAIRDNER, *Case of a Wound of the Throat in which the Trachea and Œsophagus were divided across, and which did not terminate fatally, although the parts have not reunited.—Edinburgh Medical and Surgical Journal*, 1820, vol. xvi., p. 355.

normal condition."[1] Though inanition is a pathological condition, it represents physiological waste of the organism without the supply of material from without by which the tissues are regenerated. The phenomena which accompany complete deprivation of nutritive material are likewise present, in a degree, in insufficient alimentation. The termination is the same, and occurs when the system has been reduced to the same condition as when death occurs from absolute innutrition; the only difference being in the intensity and duration of the phenomena which precede the fatal result. If aliment be insufficient in quantity, improper in quality, or if the process of digestion and assimilation be so far interfered with as to prevent the normal regeneration of the blood, and through the blood, of the tissues, death takes place from inanition, with phenomena identical with those which occur in animals entirely deprived of food. The vital properties of the tissues demand that material, of the proper constitution and in adequate quantity, be introduced from without. A deficiency in quantity or in quality, within certain limits, is met by a diminished capacity on the part of the system for that exercise, both mental and physical, which increases waste; and consequently, the general condition of the organism is lowered, to enable it to adapt itself to the diminished supply. Nature can generally dispose of an excess of nutritive material, but cannot make up a deficiency. If, however, the quantity or quality of food be reduced below a certain point, the waste must become greater than the supply, and death takes place from inanition, more slowly, but no less certainly, than when the nutritive supply is cut off altogether.

Observations on the inferior animals, and the human subject on those occasions which have presented themselves in shipwreck, times of famine, etc., have led to a tolerably

[1] CHOSSAT. *Recherches Expérimentales sur l'Inanition*, Paris, 1843, p. 194. The term *innanitiation* is used by Chossat to express the progressive condition which results in inanition.

accurate knowledge of the phenomena which attend inanition or insufficient alimentation. The experiments of Collard de Martigny, on dogs, though undertaken with the view of determining the influence of starvation on the constitution of the blood and lymph, developed many interesting facts with regard to the general changes which take place in this condition.[1] A few years later, the phenomena of inanition and its influence upon the various organs were minutely studied by Chossat, whose exhaustive memoir received the prize of experimental physiology from the Parisian Academy of Sciences, in 1844. These researches, beside confirming the observations of Collard de Martigny, developed many new facts, and have since served as the basis of our accurate experimental knowledge on this subject.[2] Phenomena analogous to those observed in animals have been noted in the instances in which starvation has been observed in the human subject, with the addition of certain intellectual disturbances which accompany this condition.

The following are the effects of inanition, as ascertained chiefly by experiments upon the inferior animals:

Progressive diminution in the weight of the body has been invariably observed. Though the sensible excretions are very much diminished in quantity, it is none the less evident that destructive assimilation is constantly going on, even long after the process of repair has ceased. Chossat has shown that the maximum of daily loss of weight is generally at the commencement of an experiment. Sometimes it is toward the termination, but never during the intermediate period. The great loss in weight generally observed at the commencement is due to the discharge of the residue of aliment taken the day before. Without noting the first day, the daily loss from the commencement to the

[1] COLLARD DE MARTIGNY, *Recherches Expérimentales sur les Effets de l'Abstinence complète d'Alimens solides et liquides, sur la composition et la quantité du Sang et de la Lymphe.*—*Journal de Physiologie*, 1828, tome viii., p. 152.

[2] CHOSSAT, *Recherches Expérimentales sur l'Inanition*, Paris, 1843.

fatal termination does not present any considerable variation. The minimum loss of weight is never at the commencement, but generally at the middle of an experiment.[1] The same observer noted that the proportionate loss of weight was remarkably uniform, even in different classes of animals. In experiments made upon birds, Guinea-pigs, and rabbits, the almost uniform result was death when the loss reached had four-tenths of the original weight.[2] This rule is somewhat modified by obesity, under this condition the loss of fat beyond the usual quantity being added to the ordinary loss of four-tenths. In a few instances the proportionate loss was increased so as to amount to five-tenths of the weight, but this appeared to be the limit. By reference to the table,[3] it is seen that the two pigeons which the author specially alludes to as very fat, and in which the loss was over five-tenths of the weight, lived respectively $16\frac{72}{100}$ and $20\frac{42}{100}$ days; the average duration of life in the animals of this class being a little more than ten days. This would indicate that, other things being equal, obesity gives a somewhat increased power of resistance to inanition.

Age seems to have a more marked and important influence upon the power of resistance to inanition and the proportionate loss of weight before death occurs, than any other circumstance. In a number of experiments upon turtle-doves, in which they were divided into three classes: 1, the young; 2, those of medium age; and 3, the adult, the following results were obtained:

In the first class, death took place in $3\frac{7}{100}$ days, after a proportionate loss of weight of $\frac{25}{100}$; in the second, death occured in $6\frac{12}{100}$ days, after a proportionate loss of $\frac{362}{1000}$; and

[1] CHOSSAT, *op. cit.*, p. 16.

[2] In the observations of Chossat on some of the cold-blooded animals (reptiles and fishes), it was found that though life continued for a very long period—an average of 226 days—death occurred when the loss of weight had reached the point at which it takes place in warm-blooded animals.—(*Op. cit.*, p. 46.)

[3] *Op. cit.*, p. 12.

in the last class, death occurred in $13\frac{36}{100}$ days, after proportionate loss of $\frac{463}{1000}$.[1]

This corresponds with all recorded observations concerning the influence of age on the power of resistance to inanition, in the human subject, as well as in the inferior animals. During the earlier periods of life, especially before the system has attained its perfect development, aliment is demanded, not only to repair waste, but for growth; and at this time, when the demand for food is greatest, the organism is least able to bear total deprivation, insufficient quantity, or inferior quality of food.

All parts of the organism are by no means equally affected by inanition. As an invariable rule, the fat disappears almost completely. The blood is diminished about three-quarters, and the digestive organs more than one-half. The muscular system is diminished nearly one-half. The weight of the nervous system is least affected.

The following table gives the proportionate loss of the different parts of the body:[2]

Loss per 100 *of different parts of the Body in Inanition.*

Parts that lose more than the mean, $\frac{4}{10}$.		Parts that lose less than the mean, $\frac{4}{10}$.	
Fat	0·933	Stomach	0·397
Blood	0·750	Pharynx, œsophagus	0·342
Spleen	0·714	Skin	0·333
Pancreas	0·641	Kidneys	0·319
Liver	0·520	Respiratory apparatus	0·222
Heart	0·448	Osseous system	0·167
Intestines	0·424	Eyes	0·100
Muscles of locomotion	0·423	Nervous system	0·019

After death the stomach is found small and contracted, the intestinal canal is reduced in calibre, and its length is diminished nearly one-third ($\frac{281}{1000}$). The digestive fluids, which are only secreted when food is contained in the ali-

[1] CHOSSAT, *op. cit.*, p. 28. [2] Ibid., p. 92.

mentary canal, are necessarily absent; but the bile, which is an excretion as well as a secretion, is still found in the gall-bladder, but is apparently concentrated. In some of the observations of Collard de Martigny, urine was found in the bladder, but it contained no urea. Lassaigne found urea in the urine of an insane person who had not eaten for eighteen days.[1]

The fæces are discharged infrequently, and are scanty and hard, except in certain cases when diarrhœa sets in toward the close of life. Diarrhœa was noted, occurring at this time, in some of the observations of Chossat.

One of the most marked and important changes in inanition is diminution in quantity and impoverishment of the blood. Collard de Martigny observed the quantity of blood to undergo diminution to such an extent that the skin and some of the muscles, when incised, discharged no blood, but only a little serum, sometimes colorless and sometimes slightly rose-colored. He is of the opinion that during the later periods of inanition, many of the tissues receive no blood.[2] It is evident that when the quantity of blood has become so much reduced, the process of nutrition in many parts must be nearly abolished.

The general effect of inanition upon the circulation is to diminish the force and frequency of the heart's action, except during the cerebral excitation, which is so frequent during the early periods of starvation. The heart becomes very much atrophied, being reduced in weight nearly one-half. In a man convicted of murder and condemned to death, who allowed himself to die of starvation, taking nothing but water for sixty-three days, the pulse descended to thirty-seven beats per minute.[3]

After a certain period of complete abstinence, it is impossible to restore the powers of life by the administration

[1] Collard de Martigny, *op. cit.*, p. 157.

[2] Ibid., p. 168.

[3] Bérard, *Cours de Physiologie*, Paris, 1848, tome i., p. 529.

of food. This has been observed in persons rescued from immediate starvation, who, in the last stages, can only be temporarily revived. Magendie, in experimenting upon the nutritive powers of different articles of food, observed in a dog that had been fed exclusively on butter, all the phenomena which accompany inanition. This animal died of starvation on the thirty-sixth day, although on the thirty-second day he was given an abundance of meat, which he continued to eat for two days.[1]

The effect of inanition on respiration is to gradually diminish the number of respiratory acts, except during the stages of cerebral excitation, and, according to Chossat, near the fatal termination, when the respiration is sometimes panting. The exhalation of carbonic acid is gradually and progressively diminished. In an observation by Bidder and Schmidt on a cat, the exhalation of carbonic acid was gradually diminished, until just before the death of the animal (eighteen days), it was reduced a little more than one half.[2] After a few days of complete inanition, or in persons who have been subjected for some time to insufficient alimentation, the breath becomes insufferably fetid and offensive. In the instance reported by Dr. Soviche of eight men who were shut up in a coal mine for nearly six days, with but a half-pound of bread, a bit of cheese, and two glasses of wine, the offensive character of the pulmonary exhalations was one of the greatest sources of suffering.[3]

The influence of progressive inanition upon the animal temperature is very marked. The organism seems to lose the power of maintaining that uniform temperature which is peculiar to warm-blooded animals. In almost all instances of inanition in the human subject, a considerable

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 502.

[2] See vol. i., Respiration, p. 434.

[3] SOVICHE, *Extrait du Rapport sur les huit Mineurs enfermés pendent cent trente-six heures dans la Houillière du bois Monzil.—Journal des Connaissances Médico-Chirurgicales*, Paris, 1836–1837, tome iv., p. 119.

diminution in temperature has been noted. In the case of the murderer already referred to,[1] the temperature was lowered to 75° Fahr. The observations of Chossat on this subject are very exact and satisfactory. He commenced by noting the average normal temperature of the animals to be experimented upon, with the variations at different times of the day. In pigeons he found that the maximum of temperature (108°) occurred at mid-day; the minimum, at midnight, was 106.66°, giving an extreme variation of 1.34° Fahr. This variation was independent of the surrounding temperature. During the progress of inanition, the daily variation was increased to 5.9°.[2] There was also a very slight but well-marked diminution in the absolute temperature. It was found, also, that the animals recovered from the diminution in temperature which occurred at night with more difficulty than during normal alimentation, and the periods of minimum temperature were unusually prolonged.

All these facts point to a progressively diminished capacity of maintaining the independent temperature of the body during inanition. Immediately preceding the fatal termination, the diminution in temperature became very rapid, the rate, in the observations on turtle-doves, being from 7° to 11° per hour. Death usually occurred when the diminution had amounted to about 30°.[3]

[1] See p. 28.

[2] *Op. cit.*, p. 123.

[3] The experiments of Chossat on the effects of artificial warmth on animals in the last stages of inanition, when the temperature had been reduced nearly to the point at which death occurs, are of great interest. In some of the animals, artificial heat, with food, restored the vital powers so that they were able to digest the food, the muscular power returned, and they finally recovered. In nearly all, even after the inanition had proceeded so far that muscular power was entirely lost and death was imminent, partial restoration was accomplished. They generally moved about with animation, were able in some instances to fly, took food when it was presented to them, and digested it, though this process took place more slowly than in health. Digestion, however, did not continue when the artificial warmth was suspended. The heat thus acquired was found to be easily lost, and did not present that degree of uniformity which characterizes the normal animal tempera-

After a certain period of inanition, febrile movement and general agitation occur; and there is almost always disturbance of the mental faculties, amounting sometimes to furious delirium. Frequently, however, the delirium is of a mild character, with hallucinations. There are cases in which there is no marked mental disturbance, but these are generally in persons who voluntarily suffer starvation. In a dog experimented upon by Collard de Martigny, which died on the thirty-fifth day, from the eleventh to the nineteenth day the animal was in a furious condition, gnawing almost constantly at the bars of the cage. This was followed by a condition of great debility, which continued, with short periods of agitation, until death. During inanition, both in man and in the inferior animals, there is very little sleep.

The length of time that life continues after complete deprivation of food and drink is very variable. The influences of age and obesity have already been referred to. Without citing the numerous individual instances of starvation in the human subject which have been reported, it may be stated in general terms, that death occurs after from five to eight days of total deprivation of food. In 1816, one hundred and fifty persons, wrecked on the frigate Medusa, were exposed on a raft in the open sea for thirteen days. At the end of this time only fifteen were found alive. One of the survivors, M. Savigny, gave, in an inaugural thesis, a very instructive and accurate account of this occurrence, which has been very generally quoted in works of physiology. Authentic instances are on record where life has been prolonged much beyond the period above mentioned; but they generally occurred in persons who were so situated as not to suffer from cold, which the system under this condition has very little power to resist. In these cases, also, there was no muscular exertion, and water was generally

ture. For a full discussion of these interesting questions, the reader is referred to the work of Chossat, p. 155 *et seq.*

taken in abundance.[1] All of these circumstances have an important influence in prolonging life.

Bérard quotes the example of a convict who died of starvation after sixty-three days, but in this case water was taken. The instance of eight miners who survived after five days and sixteen hours of almost complete deprivation of food has already been referred to. Bérard also quotes from various authorities instances of deprivation of food for periods varying from four months to sixteen years. All of the subjects were females, and the histories of such cases, reports of which are by no means uncommon, belong properly to psychology; as they are undoubtedly examples of that morbid desire to excite sympathy and interest which is sometimes observed, and which leads to the most adroit and persevering efforts at deception.[2]

The observations of Chossat on the duration of life in inanition show great variations in the different classes of animals. In experiments on birds, chiefly turtle-doves and pigeons, death occurred, on an average, after $9\frac{35}{100}$ days of complete deprivation of food and drink. In Guinea-pigs and rabbits, the same observer noticed an average duration of $9\frac{22}{100}$ days.[3] It has generally been noticed that life is more prolonged in carnivorous than in herbivorous animals. In

[1] In the *Social Science Review and Journal of Sciences*, London, edited by Dr. B. M. Richardson, we find the following note: "We ourselves knew an instance in which a man with a disordered mind refused all food for thirty days; after a short return to food, again refused for thirty-six days. But in this instance, on the second occasion, the sufferer died, although he had recommenced to swallow light nourishment. Ed." (1864, vol. i., New Series, p. 180.)

[2] From time immemorial the credulous have periodically been startled with reports of wonderful cases in which persons (generally females) have lived for an incredible time without food. A curious specimen of these histories is an account of the case of a girl, ten years of age, who lived without food and drink, and in whom development, &c., seemed to be normal. This was testified to by a learned physician, in 1542. (*De puella, quæ sine cibo et potu vitam transigit, brevis narratio, teste et auctore* GERARDO BUCOLDIANO PHYSICO REGIO, Parisiis, Ex officina Rob. Stephani typographi Regii, M.D.XLII. Cum privilegio Regis.)

[3] *Op. cit.*, p. 31.

one of the dogs experimented upon by Collard de Martigny, death occurred on the thirty-fifth day, and, in another, on the twenty-seventh day. The average duration of life in rabbits was from ten to twelve days.[1] Leuret and Lassaigne observed that dogs, kept in a warm and dry place, lived, on an average, thirty days without food or drink. A dog that was kept in a dark and damp place lived for forty days.[2] From thirty to thirty-five days, therefore, may be taken as the average duration of life in dogs deprived entirely of food and drink. This fact it is important to bear in mind in connection with observations on the nutritive value of different articles of food.

Chossat states, as the result of his observations, that the duration of life in inanition being equal to the total loss of weight divided by the average daily loss, in adult animals it is equal to $\frac{4}{10}$ of the weight of the body divided by the average daily loss.[3] This formula is highly important in a practical point of view; for, in conditions of the system in which inanition is threatened, it is easy to estimate the probable duration of life (if we fear that death may occur from inanition alone), by dividing the total loss of weight which will probably produce death, by the average daily loss; and any thing which will diminish the average daily loss, we may reasonably suppose will retard the fatal termination.

Insufficient Alimentation. — When alimentation is reduced below the standard at which life can be maintained, whether it be from diminished quantity or improper quality of food, the phenomena are very much like those which follow complete abstinence; and, curiously enough, experiments on animals have shown that death takes place when the weight is reduced by about the same proportion as in absolute in-

[1] *Loc. cit.*

[2] LEURET ET LASSAIGNE. *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion.* Paris, 1825, p. 210.

[3] CHOSSAT, *op. cit.*, p. 34.

nutrition. Under these circumstances, the amount of food which is taken diminishes, more or less, the proportionate daily loss of weight, and thus retards the fatal result.

The effects of insufficient alimentation in man have often been observed in times of famine; the sad details of which have been given in graphic accounts by various European writers. The history of our own country during the late civil war affords an example, the most appalling on record in any country and in any age, of the sufferings of thirty thousand men exposed within an area of twenty-seven acres to the effects of insufficient diet, conjoined with exposure, without protection, to the vicissitudes of the weather, and the frightful filth and other inevitable results of such excessive crowding.

In a report by Prof. Ellerslie Wallace, of Philadelphia, to Prof. Valentine Mott, the chairman of a committee appointed by the United States Sanitary Commission to inquire into the condition of United States officers and soldiers, prisoners of war, the following is given as the average diet in Southern prisons:

"The meat was irregularly given; not often daily, and to some only at intervals of days, or even several weeks, and when meat was served, the bread was, in many instances, diminished.

"About half a pint of soup, containing sweet potatoes, or generally beans or peas, in amount about two ounces, was sometimes given, with or without meat in different cases. The beans and peas were occasionally given raw and dry.

"The maximum amount of solid food for one day, described, was	10 oz. bread.
	6 oz. beef.
"With half a pint of soup made of the water in which the beef was boiled, and containing about two ounces of beans or peas, and therefore representing	2 oz.
"Total, . .	18 oz

"The minimum amount was about .	.	4 oz. bread.
		1 oz. beef.
"Total, .	.	5 oz."[1]

Assuming the amount of solid food required to keep the system of an adult male in proper condition to be from thirty to forty ounces, it is seen that even the maximum amount above given is so far insufficient for the purposes of nutrition, that death from inanition must result, sooner or later, in the majority of instances. This is assuming that the food be of proper quality; while the testimony taken by the commission showed that the quality was always inferior, generally disgusting, and that no variety of diet was afforded.

The effects of insufficient food upon the power of resisting cold was one of the most marked phenomena. Even in the mild climate of the South, frost-bite and gangrene of the extremities were very frequent. These occasional results, taken in connection with the extreme emaciation, the peculiar mental condition, etc., which go to make up the general aspect of inanition, presented a picture more distressing than can well be imagined. The description by De Meersman of the famine in Belgium in 1846 and '47, though it may seem

[1] *Narration of Privations and Sufferings of United States Officers and Soldiers while Prisoners of War in the hands of the Rebel Authorities. Being the Report of a Commission of Inquiry, appointed by the United States Sanitary Commission. With an Appendix containing the Testimony.* Philadelphia, 1864, p. 111.

The commission consisted of Valentine Mott, M. D., LL. D., Edward Delafield, M. D., Gouverneur Morris Wilkins, Esq., Ellerslie Wallace, M. D., Hon. J. I. Clark Hare, and Rev. Treadwell Walden. The statement quoted from the report of Dr. Wallace was corroborated by the sworn testimony of numerous officers and men who had been prisoners of war, and the facts were admitted by many of the public authorities directly or indirectly in charge of the prisoners, so that there can be no doubt of their general accuracy. (See reports and testimony of surgeons and others in charge of prisoners, in the trial of Henry Wirtz.)

highly colored, must, judging from the experience in this country, even fall short of the reality.[1]

"What was striking in the first place," says De Meersman, "during the famine mentioned above, was the extreme emaciation of the body, the livid pallor of the countenance, the hollow cheeks, and, above all, the expression of the eye, of which one could not lose the remembrance when it was once seen. There was, indeed, a strange fascination in that eye, in which all the vitality of the individual seemed to be contained, which glitters with a feverish light; the pupil, enormously dilated, is fixed upon you without winking, and with an interrogative astonishment, in which kindliness is mingled with fear. The movements of the body are slow; the gait is uncertain; the hand trembles; the voice, almost extinct, is tremulous. The intelligence is profoundly affected; answers are painful; memory, in the majority, is almost lost. Interrogated concerning the sufferings they endure, these unfortunates answer that they do not suffer, but that they are hungry!

"The breath is extremely fetid; the tongue thin, pointed, elongated, tremulous, almost always red; the point, often aphthous, is covered with a yellowish and opaque coating; the epigastrium is retracted, and the skin in that region is, so to speak, drawn to the vertebral column; it sometimes happens that the epigastrium is distended by meteorism; the touch then discovers organic engorgements in one part and another of the abdomen. Respiration is slow, not deep, and often interrupted by sighs. The pulse, sometimes very frequent, sometimes remarkably slow, is easily compressed, of astonishing smallness, and disappears under the finger. The secretions are all affected by the alterations in the blood, which is their common source; but above all, the perspiration, which is greatly modified. The skin was dry, yellow,

[1] Dr. Wallace (*loc. cit.*) alludes to the description of De Meersman as giving a "singularly accurate description" of the condition of exchanged United States soldiers.

resembling parchment; the exhalation, which in the ordinary condition takes place insensibly from the entire surface, is effected in this case in a dry way. The pores of the skin gave out a viscid powder, which, accumulating and becoming concreted, covered the body with a blackish crust, pulverulent and horribly fetid."[1]

To these phenomena may be added occasional perforation of the cornea, scorbutus in its various forms, gangrena oris, particularly in children, disturbances of the menstrual function, and abortion. The number of births has always been observed to be very small in communities suffering from insufficiency of food.

Through the kindness of Prof. W. H. Van Buren, of the United States Sanitary Commission, we have been enabled to make use of a MS. report to the Richmond authorities (now the property of the Commission) on the condition of United States soldiers, prisoners of war at Andersonville, by Prof. Joseph Jones, of Augusta, Georgia.[2] Dr. Jones is well known to the profession as the author of several physiological papers of interest published in the "American Journal of Medical Sciences," and by the Smithsonian Institute. From a perusal of this report, and from the scientific position and ability of its author, we are convinced that it is an accurate and careful statement of facts observed by one who had every opportunity and facility for full investigation. Though the investigations were made chiefly with reference to the diseases which prevailed among these unfortunate men, as regards many physiological points, it is the most

[1] DE MEERSMAN, in LONGET, *Traité de Physiologie.* Paris, 1861, tome i., p. 25.

[2] *Investigations upon the Diseases of the Federal Prisoners confined in Camp Sumpter, Andersonville, Ga., instituted with a view to illustrate chiefly the Origin and Causes of Hospital Gangrene, the Relations of Continued and Malarial Fevers, and the Pathology of Camp Diarrhœa and Dysentery.* By JOSEPH JONES, M. D., Professor of Medical Chemistry in the Medical College of Georgia, at Augusta, and formerly Surgeon in the Provisional Army of the Confederate States; in three volumes, Manuscript. Augusta, Ga., 1865–'66.

complete scientific history of inanition ever written, deduced from data which are, and probably always will be, unparalleled in magnitude. The pathological questions will be fully considered in one of the volumes on the Medical and Surgical History of the Rebellion, now in course of preparation under the direction of the Commission; and in this connection, will be considered, generally in the author's own words, the points which bear mainly on the effects of insufficient alimentation, though the other circumstances under which the prisoners were placed must necessarily be taken into account.

The following extract from an official report by Dr. Jones, dated October 19, 1864, gives an idea of the sanitary condition under which the prisoners were placed:

"Immediately after the brief report upon hospital gangrene had been forwarded to the surgeon-general, I repaired to Camp Sumpter, Andersonville, Georgia, and instituted a series of investigations upon the diseases of the Federal prisoners.

"The field was of great extent and of extraordinary interest. There were more than five thousand (5,000) seriously sick in the hospital and stockade, and the deaths ranged from ninety to one hundred and thirty each day. Since the establishment of this prison, on the 24th of February, 1864, to the present time, over ten thousand Federal prisoners have died: that is, near one-third of the entire number have perished in less than seven months. I instituted careful investigations into the condition of the sick and well, and performed numerous post-mortem examinations, and executed drawings of the diseased strictures. The medical topography of Andersonville and the surrounding country was examined, and the waters of the streams, springs, and wells around and within the stockade and hospital carefully analyzed.

"Diarrhœa, dysentery, scurvy, and hospital gangrene were the diseases which have been the main causes of the

extraordinary mortality. The origin and causes of the hospital gangrene which prevailed to so remarkable a degree, and with such fatal effects amongst the Federal prisoners, engaged my most serious and earnest consideration. More than *thirty thousand* men crowded upon *twenty-seven* acres of land, with little or no shelter from the intense heat of a Southern summer, or from the rain and dew, with coarse corn-bread from which the husk had not been removed, with scant supplies of fresh meat and vegetables, with little or no attention to hygiene, with festering masses of filth at the very doors of their rude dens and huts, with the greater portion of the banks of the stream flowing through the stockade a filthy quagmire of human excrements alive with working maggots:—generating by their own filthy exhalations and excretions an atmosphere that so deteriorated and contaminated their solids and fluids, that the slightest scratch of the surface, even the bites of small insects, were frequently followed by such rapid and extensive gangrene, as to destroy extremities and even life itself. A large number of operations have been performed in the hospital on account of gangrene following slight injuries and mere abrasions of the surface. In almost every case of amputation for gangrene, the disease returned, and a large proportion of the cases have terminated fatally. I recorded careful observations upon the origin and progress of these cases of gangrene, and examined the bodies after death, and noted the pathological changes of the organs and tissues. All these observations, together with the drawings, will be forwarded to the surgeon-general, at the earliest possible moment."[1]

In vol. i., p. 213, Dr. Jones gives the ration of the prisoners. This was probably the regular ration, which was undoubtedly lessened at times, for the evidence taken by the committee appointed to investigate the condition of

[1] *Report*, vol. i., Preface, pp. 12, 13.

exchanged prisoners shows that the average was much less.[1]

"5th, *Diet.*—The ration consists of $\frac{1}{3}$lb. bacon, $1\frac{1}{4}$lb. meal. The meal is unbolted, and when baked, the bread is coarse and irritating, producing diseases of the organs of the digestive system (diarrhœa and dysentery). The absence of vegetable diet has produced scurvy to an alarming extent, especially among the old prisoners."

The following extracts show the effects of this insufficient diet upon the constitution of the blood, upon the appetite, and, what is most mournfully interesting, upon the intellectual faculties:

"5*th. From the sameness of the food and from the action of the poisonous gases in the densely crowded and filthy stockade and hospital, the blood was altered in its constitution, even before the manifestation of actual disease.*

"In both the well and the sick, the red corpuscles were diminished; and in all diseases uncomplicated with inflammation, the fibrinous element was deficient. In cases of ulceration of the mucous membrane of the intestinal canal, the fibrinous element of the blood appeared to be increased, whilst in simple diarrhœa, uncomplicated with ulceration, and dependent upon the character of the food, and the existence of scurvy, it was either diminished or remained stationary. Heart-clots were very common, if not universally present, in the cases of ulceration of the intestinal mucous membrane, whilst in the uncomplicated cases of diarrhœa and scurvy, the blood was fluid and did not coagulate readily; and the heart-clots and fibrinous concretions were almost universally absent.

"From the watery condition of the blood, there resulted various serous effusions, into the pericardium, into the ventricles of the brain, and into the abdominal cavity.

"In almost all the cases which I examined after death,

[1] See page 34.

even in the most emaciated, there was more or less serous effusion into the abdominal cavity." * * *—(Vol. iii., p. 150.)

"6th. *The impoverished condition of the blood, which led to effusions within the ventricles of the brain, and around the brain and spinal cord, and into the pericardial and abdominal cavities, was gradually induced by the action of several causes, but chiefly by the character of the food.*

"The Federal prisoners, as a general rule, had been reared upon wheat bread and Irish potatoes; and the Indian corn, so extensively used at the South, was almost unknown to them as an article of diet, previous to their capture. Owing to the impossibility of obtaining the necessary sieves in the Confederacy, for the separation of the husk from the corn meal, the rations of the Confederate soldiers as well as of the Federal prisoners consisted of unbolted corn-flour, and meal, and grist; this circumstance rendered the corn bread still more disagreeable and distasteful to the Federal prisoners. Whilst Indian meal, even when prepared with the husk, is one of the most wholesome and nutritious forms of food, as has been clearly shown by the health and rapid increase of the Southern population, and especially of the negroes, previous to the present war, and by the strength, endurance, and activity of the Confederate soldiers, who were throughout the war confined, to a great extent, to unbolted corn-meal; it is nevertheless true, that those who have not been reared upon corn meal, or who have not accustomed themselves to its use gradually, become excessively tired of this kind of diet when suddenly confined to it without a due proportion of wheat bread. Large numbers of the Federal prisoners appeared to be utterly disgusted with Indian corn, and immense piles of corn bread could be seen in the stockade and hospital enclosures. Those who were so disgusted with this form of food that they had no appetite to partake of it, except in quantities insufficient to supply the waste of

the tissues, were of course in the condition of men slowly starving, notwithstanding that the only farinaceous form of food which the Confederate States produced in sufficient abundance for the maintenance of armies, was not withheld from them. In such cases an urgent feeling of hunger was not a prominent symptom; and even when it existed at first, it soon disappeared, and was succeeded by an actual loathing of food. In this state the muscular strength was rapidly diminished, the tissues wasted, and the thin, skeleton-like forms moved about with the appearance of utter exhaustion and dejection. The mental condition, connected with long confinement, with the most miserable surroundings and with no hope for the future, also depressed all the nervous and vital actions, and was especially active in destroying the appetite. The effects of mental depression and of defective nutrition were manifested not only in the slow, feeble motions of the wasted, skeleton-like forms, but also in such lethargy, listlessness, and torpor of the mental faculties, as rendered these unfortunate men oblivious and indifferent to their afflicted condition. In many cases, even of the greatest apparent suffering and distress, instead of showing any anxiety to communicate the causes of their distress, or to relate their privations and their longings for their homes and their friends and relations, they lay in a listless, lethargic, uncomplaining state, taking no notice either of their own distressed condition or of the gigantic mass of human misery by which they were surrounded. Nothing appalled and depressed me so much as this silent, uncomplaining misery.

"It is a fact of great interest that, notwithstanding this defective nutrition in men subjected to crowding and filth, contagious fevers were rare, and typhus fever, which is supposed to be generated in just such a state of things as existed at Andersonville, was unknown. These facts, established by my investigations, stand in striking contrast with such a

statement as the following, by a recent English writer.[1] (Vol. iii., pp. 151–155.)

[1] Dr. Jones states in another part of his report (vol. ii., p. 14), that "but a comparatively small number of the Federal prisoners were affected with malarial fever, and the deaths from this disease amounted to but a small fraction of the deaths from all causes;" and again it is stated (p. 41), that "the comparative immunity from malarious disease among the Federal prisoners is still further shown by the small number of cases of neuralgia entered upon the sick reports: amongst the large body of Federal prisoners, with a mean monthly strength of 21,120, only 33 cases of neuralgia were reported during a period of six months."

CHAPTER II.

ALIMENTATION.

General considerations—Division of alimentary principles—Nitrogenized alimentary principles—Musculine—Albumen—Caseine—Fibrin—Gelatine and Chondrine—Vegetable albumen, fibrin, and caseine—Gluten—Non-nitrogenized alimentary principles — Sugar — Starch — Vegetable principles resembling starch—Fats and oils—Inorganic alimentary principles—Water—Chloride of sodium—Phosphate of lime—Iron.

UNDER the name of aliment, in its widest signification, it is proposed to include all articles composed of, or containing elements in a form which enables them to be used for the nourishment of the body, either by being themselves appropriated by the organism, by influencing favorably the process of nutrition, or by retarding destructive assimilation. Those principles which are themselves appropriated may be called direct aliments; and those which simply assist nutrition without contributing reparative material, together with those which retard destructive assimilation, may be termed accessory aliments. By this definition of aliment, nothing is excluded which contributes to nutrition. The air must be considered in this light, as well as water and all articles which are commonly called drinks.

In the various articles used as food, nutritious elements are frequently combined with each other and with indigestible and non-nutritious principles. The elements of the food which are directly used in nutrition are the real alimentary principles, embracing, thus, only those principles which are capable of absorption and assimilation. The ordinary food of the warm-blooded animals contains alimentary principles,

united with innutritious substances from which they are separated in digestion. This necessitates a complicated digestive apparatus. In some of the inferior animals, the quantity of nutritious material forms so small a part of the food, that the digestive apparatus is even more complicated than in the human subject. This is especially marked in the herbivora, the flesh of which forms an important part of the diet of man. In addition to what are distinctly recognized as alimentary principles, food contains many substances having an important influence on nutrition, which have never been isolated and analyzed, but which render it agreeable and give to the diet a variety which the system imperatively demands. Many of these principles are developed in the process of cooking. They will be considered, as far as practicable, in connection with the different articles of diet.

The alimentary principles belong to the inorganic, vegetable, and animal kingdoms, and are generally divided into the following classes:[1]

1. Organic nitrogenized principles (albumen, fibrin, caseine, musculine, etc.), belonging to the animal kingdom; and vegetable nitrogenized principles, such as gluten and legumine.

2. Organic non-nitrogenized principles (sugars, fats, and starch).

3. Inorganic principles.

Nitrogenized Alimentary Principles.

In the nutrition of certain classes of animals, these principles are derived exclusively from the animal kingdom, and in others, exclusively from the vegetable kingdom; but in man, who is omnivorous, both animals and vegetables contribute nitrogenized material. In both animal and vegetable food, these principles are always found combined with inorganic

[1] Incrganic and animal substances have already been considered in treating of proximate principles (see vol. i., Introduction).

matters (water, chloride of sodium, the phosphates, sulphates, etc.), and frequently with non-nitrogenized principles (sugar, starch, and fat).

Musculine.—Of the different nitrogenized principles used as food, musculine, albumen, caseine, and fibrin are the most important. Musculine, the organic principle which forms the bulk of the muscular substance, excluding the areolar tissue which binds the fibres together, and the sarcolemma, is perhaps the most important and abundant article of this class. This substance is considered by some as identical with the fibrin of the blood; but it presents many points of difference which warrant us in regarding it as a distinct principle. It is always united with more or less inorganic matter, which cannot be separated without incineration. The flesh of different animals presents wide differences in general appearance, in nutritive properties, and in flavor, which become more marked after the formation of the odorous empyreumatic substances which are developed in cooking; but the organic principle of all of them is musculine. Muscular tissue is rendered much more digestible by cooking—a process which serves to disintegrate, to a certain extent, the inter-muscular areolar tissue, and facilitate the action of the digestive fluids. The savors developed in this process have a decidedly favorable influence on the secretion of the gastric juice. It is doubtful whether pure musculine would be capable of supporting life for a long period;[1] but the muscular tissue has been shown by experiment to be sufficient for the purposes of nutrition, in the carnivora, and it undoubtedly is in man.

[1] In the report of the "Gelatine Committee" to the Institute of France, in 1841 (M. Magendie, reporter), it was shown that dogs fed on meat which had been subjected to prolonged boiling and afterward freed from fat by being pressed in paper, became emaciated, and would have died of inanition if the experiment had been persisted in. But this experiment is not entirely conclusive, as much of the nutritive principle of the musculine must have been extracted by boiling. (*Comptes Rendus*, Paris, 1841, tome xiii., p. 275.)

Of all kinds of muscular tissue, beef possesses the greatest nutritive power. Other varieties of flesh, even that of birds, fishes, and animals in a wild state, do not present an appreciable difference, as far as can be ascertained by chemical analysis; but when taken daily for a long time, they become distasteful, the appetite fails, and the system seems to demand a change of diet. The flesh of carnivorous animals is rarely used as food; and animals that feed upon animal as well as vegetable food, such as pigs or ducks, acquire a disagreeable flavor when the diet is not strictly vegetable.

Of the various methods which have been employed for the preservation of meat, salting, which is the most common, has the most unfavorable influence on its nutritive properties. Experience has shown that salted meat is much less nutritious than fresh, and the gravest effects on the nutrition of the body have followed its prolonged use as the principal article of diet. It has also been ascertained chemically, that brine extracts from the muscular tissue much of its nutritive principle.

Albumen.—This is an alimentary principle hardly second in importance to musculine. As an article of diet, it is chiefly found in the white of egg, where it exists in great quantity, and is combined with a variety of inorganic substances. Though an important alimentary principle, it cannot meet all the nutritive requirements of the organism. Numerous observations on the inferior animals, and those of Hammond on his own person,[1] have shown that pure albumen will not sustain life. The egg of the fowl, however, containing in addition to albumen a large quantity of inorganic matter, the fatty matter of the yolk, and other organic principles, is a most nutritious article of food. Albumen is the

[1] HAMMOND, *Experimental Researches relative to the nutritive value and physiological effects of Albumen, Starch, and Gum, when singly and exclusively used as Food.*—Prize Essay—*Trans. American Med. Assoc.*, 1857, and *Physiological Memoirs*, Philadelphia, 1863, p. 67.

great nutritive nitrogenized principle of the blood, and is the substance into which all the principles of this class which exist in food are converted before they are applied to the nutrition of the tissues.

Caseine.—At a certain period of life this constitutes essentially the sole nitrogenized article of food. It is found only in milk, and it exists largely in the great variety of cheeses which are manufactured from milk. In addition to caseine, milk contains butter, sugar, and a variety of inorganic principles; and is capable of supplying material for the nourishment of all parts of the organism, caseine supplying the nitrogenized principle. In the form of cheese, caseine constitutes an important article of food.

Fibrin.—Fibrin is by no means so important an article of diet as those just considered, and it very seldom forms any considerable part of our food. The same may be said of some other principles of this class, such as globuline, which is the organic principle of the blood-corpuscles; vitelline, a principle peculiar to the yolk of the egg; osteine and cartilagine. The two latter substances are generally taken after they have undergone peculiar modifications in cooking, when they are known by other names.

Gelatine and Chondrine.—After prolonged boiling, the organic principles of the bones, integuments, areolar tissue, tendons, and other structures composed of the white fibrous tissue, are dissolved and transformed into a new substance, which is called gelatine. Cartilage, treated in the same way, is in great part converted into chondrine. These two substances are artificial products, and therefore were not considered in treating of the proximate principles of the organism.[1]

The principles thus formed are soluble in hot water,

[1] See vol. i., Introduction.

rendering it slightly viscid, but on cooling, the whole mass becomes of a more or less gelatinous consistence, according to the quantity of gelatine that is present. A considerable quantity of inorganic matter, particularly phosphate of lime, is always present in combination with gelatine.

Gelatine and chondrine present slight differences as regards their chemical reactions, in other respects being nearly identical. The sulphate of alumina, alum, and the sulphate of iron, will precipitate chondrine, but have no influence on a solution of gelatine. Tannin, or infusion of galls, added to a solution of gelatine, produces a brownish precipitate. This reaction is marked in a solution containing but one part of gelatine to five thousand of water. Both gelatine and chondrine are of indefinite chemical composition and uncrystallizable.[1] By the action of sulphuric acid, gelatine is transformed into a crystallizable substance called glycocolle, which has a sweetish taste, is soluble in water and insoluble in alcohol and ether. According to some, this is capable of being separated into alcohol and carbonic acid by fermentation.[2]

A great deal of interest was at one time attached to gelatine as an article of food, from the fact that it is formed and extracted from parts, particularly the bones, which were before regarded as comparatively useless. Indeed, the experiment of diminishing the quantity of meat, and supplying in its place the extract of bones, was made in several hospitals and manufacturing establishments in France; but this change in diet led so universally to complaints of insufficiency of food, that experiments were soon instituted with a view of determining whether gelatine really possessed any nutritive power. Without entering upon a full discussion of these exper-

[1] The formulæ generally given for these two substances are: Gelatine, $C_{13} H_{10} O_5 N_2$, and Chondrine, $C_{32} H_{26} O_{14} N_4$; but, as remarked by Longet, these formulæ are very uncertain. Chondrine is supposed by some (Mulder, Robin) to contain, in addition, a little sulphur.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 44, note.

iments, it may be stated that the introduction of gelatine as an article of diet, to the exclusion of other principles which were known to be nutritive, was always followed by loss of weight and the indications of more or less defective nutrition. In other words, the introduction of gelatine did not permit any diminution in the quantity of ordinary articles of food. The whole question was finally settled by the researches of Magendie, the reporter of the committee on gelatine, in 1841. This report embodied the results of numerous experiments on the effects of various nitrogenized principles; but the conclusions with regard to gelatine were, that taken alone it was distasteful in the highest degree, even to animals on the verge of starvation; and that even the agreeable jelly formed of different parts of the pig and the giblets of fowl, prepared by the *charcutiers* of Paris, at first taken by the animals with apparent satisfaction, was refused after a few days; and when animals were confined exclusively to this article, death took place about the twentieth day, with all the symptoms of inanition.[1]

The flavor of meat was formerly supposed to depend chiefly on a peculiar principle, called, by Thénard, osmazome. This name is now seldom used, as the substance which was so called is known to be composed of various empyreumatic nitrogenized products, with lactic acid, the lactate of soda, the inosate of potash, creatine, creatinine, and other principles, the nature of which has not been determined.

Most of the vegetable articles of food contain more or less of nitrogenized principles which resemble very closely their analogues in the animal kingdom. Some of these vegetable principles resemble those above considered so closely that they have been called respectively, vegetable albumen, fibrin, and caseine. They all, however, present certain distinguishing peculiarities.

[1] MAGENDIE, *Rapport fait à l'Académie des Sciences au nom de la Commission dite de la Gélatine.—Comptes Rendus*, Paris, 1841, tome xiii., p. 254.

Vegetable Albumen.—In the juice of most vegetables which are used as food, is found a substance, coagulable by heat and by alcohol, and having the same composition as ordinary albumen, with the exception of the equivalents of phosphorus and sulphur. This is found most abundantly in the juice of turnips, carrots, cabbages, and vegetables of this class. In wheaten flour, which contains nearly all classes of alimentary principles, it is also found, but in small quantity.

There is every reason to suppose that, as nutritive principles, vegetable and animal albumen are nearly identical. Many of the largest and strongest animals are nourished exclusively from the vegetable kingdom. The human subject, and many of the inferior animals, may be nourished at will by vegetable or by animal food. There is, however, always a physiological difference in the various nitrogenized principles, which is not appreciable by chemical analysis. The flesh of the carnivora, when used as food, is not the same as the flesh of the herbivora; and the quality of meat may be modified in many animals by changing from a vegetable to an animal diet. Though the muscular tissue of one animal may be used for the nourishment of another, the flesh of an animal thus nourished is not the appropriate food for man. We should live upon vegetable principles; taking them in part directly, and in part indirectly, or after they have been prepared and assimilated by animals. As a rule, the nutritive principles in vegetables are relatively less abundant than in animal food, and the indigestible residue is therefore greater; but man, and even the carnivorous animals, may be nourished indefinitely by appropriate articles derived from the vegetable kingdom. In man, however, the mental and physical vigor is, as a rule, notably impaired by a strictly vegetable diet.

Vegetable Fibrin and Caseine.—Many of the vegetable juices contain a spontaneously coagulable substance which has been called vegetable fibrin. This is particularly abun-

dant in the cereals. What has been said concerning fibrin, as an alimentary principle, is applicable to this substance. Its proportion in vegetables is small, unless we consider as vegetable fibrin, gluten, one of the most abundant and important of the nutritive principles contained in ordinary flour.[1]

A principle may be extracted from beans, peas, and other vegetables of this class, which is thought by many to be identical, in all respects, with caseine, and has been called vegetable caseine. In Longet we find an account of an article of food called *tao-foo*, made by the Chinese out of peas, which is apparently identical with cheese.[2] The peas are reduced to a pulp by boiling, the vegetable caseine is coagulated by rennet, and afterward treated in the same way as the analogous substance manufactured from milk. Vegetable and animal caseine have, as far as we know, identical physiological relations. Vegetable caseine is sometimes called *legumine*. It is sparingly soluble in water, is insoluble in alcohol, is not coagulated by heat, and is precipitated by the mineral acids and some of the mercurial and calcareous salts. It is dissolved by the vegetable acids.[3]

Another substance, supposed by some to be identical with vegetable caseine, is *amandine*. This is found widely distributed in the vegetable kingdom, but it hardly presents points of distinction from legumine, sufficient to mark it as a distinct principle.

Gluten.—In many of the vegetable grains known as cereals, there exists, in variable proportions, a highly nutritive nitrogenized substance called gluten. This is found in great abundance (from 10 to 35 per cent.) in wheat.[4] Its

[1] Gluten is a compound substance, containing several distinct alimentary principles, and cannot be considered strictly as analogous to animal fibrin.

[2] *Op. cit.*, tome i., p. 42.

[3] NYSTEN, *Dictionnaire de Médecine, par* LITTRÉ ET ROBIN. Paris, 1865. (*Légumine.*)

[4] PEREIRA, *Treatise on Food and Diet.* New York, 1843. See table of pro-

proportion in other grains is insignificant. It may be easily extracted from ordinary wheaten flour, by kneading under a stream of water, when the starch, a little sugar, vegetable albumen, mucilage, and some soluble matters are removed, and the gluten remains in the form of an adhesive, elastic, grayish-white mass. Gluten is capable of acting as a ferment, transforming starch first into dextrine, and then into sugar. It is the substance which gives the peculiar consistence and porous character to bread.

The nutritive power of gluten is so great, and it contains such a variety of alimentary principles, that dogs are well nourished and can live indefinitely on it when taken as the sole article of food. This experiment was actually made by the gelatine committee;[1] and the fact will be easily understood when we consider that it is a compound of no less than three distinct nitrogenized principles, together with fatty and inorganic matters. In one of the methods of treatment of diabetes mellitus, in which all saccharine and amylaceous matters are excluded from the food, it has been found difficult to nourish the body sufficiently and give proper variety to the diet without bread; and, under these circumstances, the use of bread composed almost exclusively of gluten has been highly successful. With proper care, a bread can be made in this way which is eminently nutritive and not unpalatable.[2]

portions of gluten in different kinds of grain, p. 97. These analyses probably give the proportion of moist gluten.

[1] *Comptes Rendus*, *op. cit.*, Paris, 1841, tome xiii., p. 280.

[2] It is easy to extract the gluten from wheaten flour, but a difficulty in the making bread from it is in the excessive "rising" which takes place in the process of baking, rendering it light, friable, and disagreeable to the taste. This difficulty may be overcome by the following process, suggested by Martin de Grenelle:

The moist gluten is desiccated at a temperature of 212° Fahr. "Thus dried and reduced to powder, it has lost in great part its tendency to expand. It may then be used like ordinary flour, kneading it with 66 parts of water to 100; a half a hundredth of yeast is added, and at the end of about a half-hour, the dough is put in, in the form of a large twist." (PAYEN, *Précis Théorique et Pratique des Substances Alimentaires*, Paris, 1865, p. 356.)

Gluten obtained by washing flour under a stream of water contains vegetable fibrin, vegetable albumen, and a substance soluble in alcohol, called *glutine*. This latter substance is found in quantity only in wheaten flour.

In the different articles of food belonging to the vegetable kingdom, there are undoubtedly many nitrogenized principles, with the distinguishing properties of which we are not yet familiar. In their relations to the body as alimentary principles, these would not possess much practical interest, even if they had all been isolated and studied; as all articles of this class are apparently transformed into one and the same nutritive principle, namely, the albumen of the blood.

Non-Nitrogenized Alimentary Principles.—The important principles belonging to this class are sugar, starch, and fat. From the fact that these are supposed by some to be exclusively concerned in keeping up the animal temperature by the oxidation of carbon, they are frequently spoken of as the carbonaceous or calorific elements of food. They are sometimes called hydro-carbons.[1]

In many respects there are marked and important differences between the nitrogenized and non-nitrogenized articles of food; and whether or not these differences relate to the nutrition of the organism, is a question which will be considered in its appropriate place. The production of animal heat, which is supposed by some to be due entirely to the action of non-nitrogenized substances, is closely connected with the function of nutrition and all that is at present known of this general process must be taken into consideration in connection with calorification. It is certain, however, that all alimentary and proximate principles which contain nitrogen, excluding the inorganic and some crystallizable organic substances, have very differ-

[1] The name hydro-carbon is strictly applicable only to the sugars and starch, which are, chemically, hydrates of carbon, containing as they do, carbon, with hydrogen and oxygen in the proportions to form water.

ent properties from those which contain no nitrogen. While the nitrogenized principles are in a state of continual change, so that it is impossible to fix upon any formula as representing their exact ultimate composition, the non-nitrogenized principles are not changed unless by the influence of some other substance known as a ferment, and have a distinct and definite chemical composition. The latter not only differ greatly from the nitrogenized principles, but most of the individual articles of this class present distinctive peculiarities in their general properties, reactions, and ultimate composition. Treating of them as alimentary principles, we have now only to do with their general properties, and the changes which they may be made to undergo out of the body.

Sugar.—A great many varieties of sugar occur in food; and this principle may be derived from both the animal and vegetable kingdom. The most common varieties derived from animals are sugar of milk and honey, beside a small quantity of liver-sugar, which is taken whenever this part is used for food. The sugars derived from the vegetable kingdom are cane-sugar, under which head may be classed all varieties of sugar except that obtained from fruits, and grape-sugar, which comprises all the varieties existing in fruits.[1] In addition, an impure uncrystallizable residue, obtained in the manufacture of the different varieties of cane-sugar, called molasses, is a common article of food. The following are the formulæ for the different varieties of sugar in a crystalline form:

Cane-Sugar,	$C_{12}H_{11}O_{11}$
Milk-Sugar,	$C_{12}H_{12}O_{12}$
Grape-Sugar (Glucose),	$C_{12}H_{14}O_{14}$

All varieties of sugar have a peculiar sweet taste; they

[1] M. Buignet has demonstrated the presence of cane-sugar in quite a number of fruits, always, however, in combination with a certain proportion of grape-sugar. (PAYEN, *op. cit.*, p. 241.)

are soluble in water and in alcohol; they are inflammable, leaving an abundant carbonaceous residue, and giving off a peculiar odor of caramel; and are capable of being converted, in contact with ferments and with nitrogenized principles, into alcohol and carbonic acid, and into lactic acid. They are also capable of other modifications when treated with the mineral acids, or with alkalies, which are interesting more in a chemical than a physiological point of view.[1] Of all the varieties of sugar, that made from the sugar-cane is the most soluble, the sweetest, and most agreeable. Beet-root sugar, so extensively used in France, is perhaps as agreeable, but not so sweet.

Much of the sugar used in the nutrition of the organism is formed in the body from the digestion of starch. This transformation of starch may be effected artificially. The sugar thus formed is called glucose, and is identical in composition with grape-sugar. Except in the milk during lactation, this is the only form in which sugar exists in the organism, all the sugar taken as food being converted into glucose before it is taken into the blood.

Starch.—A non-nitrogenized principle, closely resembling sugar in its ultimate composition ($C_{12}H_{10}O_{10}$), is contained in abundance in a great number of vegetables. It is found particularly in the cereals (wheat, rye, corn, barley, rice, oats), in the potato, chestnuts, and in the grains of leguminous plants (beans, peas, lentils, kidney-beans), in the tuberous roots of the yam, tapioca, and sweet-potato, in the roots of the *Maranta arundinacea*,[2] in the sago-plant, in the bulbs of orchis.[3] In the cereals, after desiccation, the proportion of starch is, in general terms, between sixty and

[1] The various tests for sugar have been considered in vol. i. (Introduction).

[2] The creeping roots from which the substance known as arrow-root is manufactured.

[3] PAYEN, *Précis Théorique et Pratique des Substances Alimentaires*, Paris, 1865, p. 232.

seventy parts per hundred. It is most abundant in rice, which contains, after desiccation, 88·65 parts per 100.[1]

The proportion of starch in the various vegetable articles has assumed considerable interest from the fact that in the mode of treatment of diabetes already referred to, in which it is the object to prevent the ingestion of sugar or any thing which may be transformed into sugar, it is proper to allow certain vegetables, which contain no starch, or a very small quantity. Payen gives the following list of articles, arranged in order according to their proportion of starch:

"1. Parsnips, which contain in their natural condition 6, and desiccated, 29·38 parts per 100 of starch;

"2. Carrots;

"3. Pods of string-beans: starch exists in the substance of the walls of the *carpelles*,[2] as well as in the young green beans; but it is not found in appreciable quantity in the parenchyma which surrounds the beans;

"4. Turnips: starch is found principally in the cortical portion of these tuberous roots;

"5. Cabbages: the presence of starch in very small quantity is recognized in the ribs of the leaves;

"6. Cauliflowers: it is at the upper extremity of the atrophied buds, forming the *head* of this horticultural product, that slight traces of starch are observed.

"We have not found starch in *romaine*, lettuce, chiccory, in the leaves of sorrel, spinage, in asparagus, *artichauts*, leeks, nor in the large, early, white onion."[3]

[1] Ibid., p. 265.

[2] This is a-name given by De Candolle to the elementary organs, free or adherent to each other, the reunion of which gives rise to the pistil, and each one of which has been regarded as a little leaf folded upon itself. (NYSTEN's *Dict.*)

[3] PAYEN, *op. cit.*, p. 387. In the treatment of diabetes by the exclusion of saccharine and amylaceous articles of food, it is, of course, important to secure the greatest possible variety of diet; and though this is a question of therapeutics, we have thought it not uninteresting nor inappropriate to give a list of vegetables which contain no starch, or so little that they may be supposed to furnish no material for the formation of the sugar which is discharged from the body.

Starch may be separated from many plants by simple washing, but in others in which it exists in connection with a considerable proportion of gluten, a more elaborate process is employed in commerce. The different varieties of manufactured starch, such as corn-starch, potato-starch, arrow-root, tapioca, and sago, differ only in the presence of a minute quantity of odorous and flavoring principles.

When extracted in a pure state, starch is in the form of granules, varying in size from $\frac{1}{10000}$ to $\frac{1}{400}$ of an inch, and presenting, in most varieties, certain peculiarities of form. The granule is frequently marked by a little conical excavation called the hilus, and the starch substance is arranged in the form of a concentric laminæ, the outlines of which are frequently quite distinct. When starch is rubbed between the fingers, these little hard bodies give it rather a gritty feel, and produce a crackling sound. Most chemists are of the opinion that the starch-granules are composed of a single substance, but some contend that each grain is a true vegetable organ, with an investing membrane composed of nitrogenized matter.[1] The different varieties of starch may be recognized microscopically by the peculiar appearance of the granules.

The presence of even a minute quantity of starch in any mixture which is not alkaline may be readily determined by the addition of iodine, which unites with the starch, producing an intense blue color. The color may be destroyed by the addition of an alkali, or by the application of heat. It may be restored, however, by the addition of an acid, or, in the latter instance, it returns when the mixture is allowed to cool, if the temperature has not been carried to 212° Fahr.

Starch is insoluble in water; but when boiled with several times its volume of water, the granules swell up, become trans-

[1] BLONDLOT, *Recherches sur la Digestion des Matières Amylacées*, Nancy, 1853, p. 13

parent, and finally fuse together, mingling with the water, and giving it a mucilaginous consistence. The mixture on cooling forms a jelly-like mass of greater or less consistence. This change in starch is called hydration, and is interesting as one of the transformations which takes place in the process of digestion, when starch is taken uncooked. This change is generally effected, however, in the process of cooking.

The most interesting properties of starch are connected with its transformation, first into dextrine, and finally into glucose. This always takes place in digestion, before starch can be absorbed. In the digestive apparatus, the change into sugar is almost instantaneous; and the intermediate substance, dextrine, is not recognized. By boiling starch for a number of hours with dilute sulphuric acid, it gradually loses its property of striking a blue color with iodine, and is transformed, without any change in chemical composition, into the soluble substance called dextrine. If the action be continued, it assumes four atoms of water, and is converted into glucose. If dextrine be perfectly pure, no coloration is produced by the addition of iodine, but ordinarily it contains starch imperfectly transformed, and iodine produces a reddish color. The change of starch into dextrine may be effected by a dry heat of about 400° Fahr., a method which is commonly employed in commerce.

The most effectual method of producing this transformation of starch, aside from the process of digestion, is by the action of a peculiar vegetable substance called diastase. This substance is produced in the process of germination of many of the vegetables containing starch.[1] Its exact chemical composition is unknown. One part of diastase will effect the transformation of one hundred parts of starch, which would require thirty times the quantity of sulphuric acid.

[1] Diastase is a white, amorphous, nitrogenized substance, insoluble in alcohol, soluble in water, and is extracted from barley, oats, grain, and potatoes, in process of germination. Its action upon starch is most energetic at from 150° to 167° Fahr.

What has been said regarding sugar as an alimentary principle will apply to starch. Though an abundant and important article of diet, it has been demonstrated by Hammond[1] and others to be insufficient of itself for the purposes of nutrition.

Vegetable Principles resembling Starch.—In certain vegetables, substances isomeric with starch, but presenting slight differences as regards general properties and reactions, have been described, but they possess no very great interest as alimentary principles, and demand only a passing mention. These are, inuline, lichenine, cellulose, pectose, mannite, mucilages, and gums.

Inuline is found in certain roots. It is capable of being converted into sugar, but does not pass through the intermediate stage of dextrine. It differs from starch in being very soluble in hot water, and in striking a yellow instead of a blue color with iodine.

Lichenine is found in many kinds of edible mosses and lichens. It differs from starch only in its solubility.

Cellulose is a substance, generally regarded as identical in all plants, which forms the basis of the walls of the vegetable cells. It exists in greater or less abundance in all vegetables. It is less easily acted upon by acids than starch, but is capable, when treated with concentrated sulphuric acid, of being converted first into dextrine, and finally into sugar. It is only in soft and recent vegetable products that it can be regarded as an alimentary principle.

Pectose is a principle which exists, mingled with cellulose, in unripe fruits, carrots, turnips, and some other vegetables of this class. Its composition has not been determined. In ripe fruits it is found transformed into a soluble substance called pectine. This transformation may be effected artificially by the action of acids and heat. Pectine may be pre-

[1] *Op. cit.*

cipitated in a gelatinous form from the juices of fruits by alcohol.

Mannite is a sweetish principle found in manna, mushrooms, celery, onions, and asparagus. Manna in tears is composed of this principle in nearly a pure state. It is perhaps more analogous to sugar than to starch, but is not capable of fermentation and has no influence on polarized light.

Gums and mucilages may enter to a certain extent into the composition of food, but they can hardly be considered as alimentary principles. Gums are found exuding from certain trees, first in a fluid state, but becoming hard on exposure to the air. A viscid, stringy mucilage is found surrounding many grains, such as the flax-seed, quince-seeds, and exists in various kinds of roots and leaves. Both gums and mucilages mix readily with water, giving it a consistence called mucilaginous. They have the same composition as starch.

Experiments have shown that gum passes through the alimentary canal unchanged, and has no nutritive power.[1] It is said that gummy exudations from trees form an important part of the food of certain savage African tribes; but it must be remembered that in this condition the exudation is impure and contains many other substances. Gum is mentioned in this connection from the fact that it is frequently used in the treatment of disease, and is thought by many to possess nutritive properties.

Fats and Oils.—Fatty or oily matters, derived from both

[1] Boussingault, out of fifty grammes of pure gum fed to a duck, extracted forty-six from the fæces. (*Mémoires de Chimie Agricole et de Physiologie*, Paris, 1854, p. 232.) Dr. Hammond ascertained by experiments on his own person that gum is not only innutritious, but, when taken in quantity, is irritating and injurious. He attempted to live for ten days on pure gum and water, but was forced to discontinue his experiment at the end of the fourth day, from excessive hunger, extreme debility, and fear of inducing serious disease. (*Experimental Researches relative to the Nutritive Value and Physiological Effects of Albumen, Starch, and Gum, when singly and exclusively used as Food.—Trans. American Med. Assoc.*, 1857.)

the animal and vegetable kingdom, constitute an important division of the articles of food. As a proximate principle, fat is found in all parts of the body, with the exception of the bones, teeth, and fibrous tissues. It necessarily constitutes an important part of all animal food, and is taken in the form of adipose tissue, infiltrated in the various tissues in the form of globules and granules of oil, and in suspension in the caseine and water in milk. Animal fat is a mixture of oleine, margarine, and stearine, in varied proportions, and possesses a consistence which depends upon the relative quantities of these principles. More or less fat always enters into the composition of food, but as a rule, it is more abundantly taken in cold than in warm climates. The ordinary diet of the Greenlander contains what would be considered in temperate climates as an enormous quantity of fat and oil, frequently in a disgusting form, and taken unmixed with other articles.

The different varieties of animal fats do not demand special consideration as articles of diet. Butter, an important article of food, is somewhat different from the fat extracted from adipose tissue, but most varieties lose their individual peculiarities in the process of digestion, and are apparently identical when they find their way into the lacteal vessels.

In the vegetable kingdom, fat is particularly abundant in seeds and grains, but it exists in quantity in some fruits, as the olive. Here it is generally called oil. Its proportion in linseed is 20 per cent.; in rape-seed, 35 to 40 per cent.; in hemp-seed, 25 per cent.; and in poppy-seed, 47 to 50 per cent.[1] It exists in considerable proportion in nuts, and in certain quantity in the cereals, particularly Indian corn. Its proportion in the different varieties of wheat is from 1·87 to 2·61 per cent.; in rye, 2·25 per cent.; in barley, 2·76 per cent.; in oats, 5·5 per cent.; in Indian corn, 8·8 per cent.;

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 47.

and in rice, 0·8 per cent.[1] The above is the proportion in the grains after desiccation.

Fat, both animal and vegetable, may be either liquid or solid. It has a peculiar oily feel, a neutral reaction, is insoluble in water and soluble in alcohol (particularly hot alcohol), chloroform, ether, benzine, and solutions of soaps. The solid varieties are exceedingly soluble in the oils. Treated with alkalies, at a high temperature and in the presence of water, they are decomposed into fatty acids and glycerine, the acid uniting with the base to form a soap. Alkaline, mucilaginous, and some animal fluids (particularly the pancreatic juice) are capable of holding fat in a state of minute and permanent subdivision and suspension, forming what are known as emulsions.

The composition of many of the fats and oils has never been definitely ascertained, on account of the difficulty in obtaining them in a state of absolute purity. They contain carbon, hydrogen, and oxygen, but the latter elements do not exist in the proportions to form water. The composition of stearine is $C_{71}\,H_{70}\,O_8$.

As alimentary principles, fats and oils are undoubtedly of great importance. They are supposed by many to be particularly concerned in the function of calorification. It has been proven by repeated experiments that fat, as a single article of diet, is insufficient for the purposes of nutrition.

Inorganic Alimentary Principles.—Physiological chemistry has shown that all the organs, tissues, and fluids of the body contain inorganic matter in greater or less abundance. The same is true of vegetable products. All the organic nitrogenized principles contain mineral substances which cannot be removed without incineration, and which must be considered as actually part of their substance. When new organic matter is appropriated by the tissues to supply the

[1] PAYEN, *Précis Théorique et Pratique des Substances Alimentaires*, Paris, 1865, p. 265.

place of that which has become effete, the mineral substances are deposited with them; and the organic principles, as they become effete, or are transformed into excrementitious substances and discharged from the body, are always thrown off in connection with the mineral substances which enter into their composition. This constant discharge of inorganic principles, forming as they do an essential part of the organism, necessitates their introduction with the food, in order to maintain the normal constitution of the parts. As these principles are as necessary to the proper constitution of the body as any other, they must be considered as belonging to the class of alimentary substances. This conclusion is inevitable, if alimentation be regarded as the supply of material for the regeneration of the organism.

Water.—This should be placed at the head of the list of inorganic alimentary principles. It constitutes the greatest part of the fluids which are used as drink;[1] but is seldom, if ever, taken in a pure state, all potable waters containing numerous inorganic salts in solution. A consideration of its functions as a solvent, and in giving the proper consistence to parts, belongs to the physiological chemistry of the organism.[2] It is always to be remembered, however, that water forms a part of all the organic nitrogenized principles, and is indispensable to the manifestation of their vital properties. It exists, therefore, in all the animal and vegetable nitrogenized elements of food, and serves as the vehicle for the introduction of all the inorganic salts and the soluble non-nitrogenized alimentary principles.

Chloride of Sodium.—Of all saline substances, chloride of sodium is the one most widely distributed in the animal and vegetable kingdom. It exists in all varieties of food.

[1] Water, with the substances which it holds in solution and with which it is combined, will be taken up more fully under the head of drinks.

[2] See vol. i., p. 30 *et seq.*

The quantity, however, which is taken in combination with other principles is usually insufficient for the purposes of the economy, and common salt is generally added to certain articles of food as a condiment, when it improves their flavor, promotes the secretion of some of the digestive fluids, and meets a positive nutritive demand on the part of the system. Numerous experiments and observations have shown that a deficiency of chloride of sodium in the food has an unfavorable influence on nutrition.[1]

Phosphate of Lime.—This is almost as common a constituent of vegetable and animal food as the chloride of sodium. It is seldom taken except in combination, particularly with the nitrogenized alimentary principles. Its importance as an alimentary principle has been experimentally demonstrated, it having been shown that in animals deprived as completely as possible of this substance, the nutrition of the body, particularly in parts which contain it in considerable quantity, as the bones, is seriously affected.[2]

Iron.—Hæmatine, the coloring matter of the blood, contains, intimately united with organic matter, a considerable proportion of iron. The examples of anæmia which are daily met with in practice, and are almost always relieved in a short time by the administration of iron, are proof of the importance of this substance as an alimentary principle. The quantity of iron which is discharged from the body is

[1] See vol. i., Introduction.

[2] Chossat fed pigeons for a length of time exclusively on wheat which had been carefully cleaned so as to remove every particle of calcareous matter. He found that this diet answered very well for three months; but after that time diarrhœa set in, and the animals died between the eighth and the tenth month. One of the most remarkable points in these experiments related to the condition of the bones, which became excessively thin and fragile. One animal was found with both femurs and tibias fractured; and examined after death, it was found that the bony tissue had disappeared from many parts of the sternum. None of these effects were observed when a little carbonate of lime was added to the food. (*Comptes Rendus*, Paris, 1842, tome xiv., p. 452.)

very slight; a trace only being discoverable in the urine. A small quantity of iron is frequently introduced in solution in the water taken as drink, and it is a constant constituent of milk and eggs. When its supply in the food is insufficient, it is necessary, in order to restore the processes of nutrition to their normal condition, to administer it in some form, until its proportion in the organism reaches the proper standard.

It is hardly necessary even to enumerate the other inorganic alimentary principles, as nearly all are in a state of such intimate combination with nitrogenized principles that they may be regarded as part of their substance. Suffice it to say, that all the inorganic matters which exist in the organism as proximate principles are found in the food. That these are essential to nutrition, cannot be doubted; but it is evident that by themselves they are incapable of supporting life, as they cannot be converted into either the nitrogenized or the non-nitrogenized proximate principles.

CHAPTER III.

COMPOUND ALIMENTARY SUBSTANCES.

General considerations—Aliments derived from the animal kingdom—Meats—Animal viscera—Animal products used as food—Eggs—Milk—Butter—Cheese—Fishes, reptiles, mollusks, and crustacea—Preparation of animal articles of food—Aliments derived from the vegetable kingdom—Cereal grains—Bread—Leguminous roots, leaves, seeds, etc.—Condiments and flavoring articles.

ALTHOUGH the number of distinct alimentary principles is comparatively small, the different articles used as food in the civilized world are almost innumerable. In the selection of these articles, the natural instincts of man have become so developed and modified by habit and education, that little apparently remains to indicate the character of his original tastes. The more powerful races, in their conquests and explorations, have ever regarded the knowledge of new articles and of new and improved methods of preparation of food as their most valuable acquisitions from foreign lands; until, in the centres of civilization, the luxurious diet of the epicure comprises the products of nearly every climate and soil on the face of the globe, prepared with a scientific skill which is the result of the studies and experience of ages. Though the necessary and proper diet of man must present a certain physiological variety, the articles used may be very simple. All that is requisite is that the different alimentary principles shall be present in proper quantity, and that they be not unpalatable nor in such a form as to become distasteful from monotony. In normal alimentation it is indis-

pensable that the demands of the system be regulated by exercise and proper habits of life, so that the tastes and the digestive powers may be always in a physiological condition. But this is not always the case; the incessant activity and the preoccupations of the mind frequently react on the body, and artificial appetites are easily engendered; while fancies and prejudices may become so much a part of the organization that the natural instincts are almost buried. An almost universal tendency to tempt the appetite with food in as palatable and attractive a form as possible has led to a high development of the art of cooking. The preparation of food by cooking has three great objects: one to render it as palatable as possible; another to save and utilize articles which, without skilful preparation, would be lost; and another, the most important in a physiological point of view, to improve alimentary substances as regards digestibility.

There can be hardly any doubt but that the intelligence of man is, in the main, correct in recognizing certain articles, such as tea, coffee, alcoholic beverages, tobacco, etc., as capable of temporarily supplying the place of some of the true alimentary principles, or of diminishing the demand for nourishment by retarding destructive assimilation.[1] Extraordinary physical effort, and, most of all, severe mental exercise, create demands which are not a part of mere animal existence. It must be regarded as fortunate for the development of truth and the progress of the world, that man is not made to pass his life in accordance with what might be considered as purely physiological laws. He is the only being in creation which ever seems to demand that unusual

[1] Actual experiment has demonstrated the value of tea, coffee, and occasionally alcohol, within moderate limits, as accessory alimentary principles. In this statement, an exception might be made with regard to alcohol, the abuse of which constitutes one of the greatest of human vices. But this does not alter the physiological fact of its value in nutrition, when properly used. The same may be said of tobacco, though its influence is less decided. Tea and coffee, also, are open to the objection of being frequently used to excess.

kind of nutrition in which the operation of accessory alimentary principles is so conspicuous. It cannot be denied, however, that the appetites sometimes engendered by great mental exercise very frequently lead to the most disastrous results.

Aliments derived from the Animal Kingdom.—The articles of food derived from the animal kingdom are numerous and varied. At the head of the list may be placed the different kinds of meat, a name generally applied to the flesh of the mammalia; next, the flesh of birds, those most commonly used being domesticated, like the fowl, turkey, etc.; next, the flesh of fishes, a great variety of which are edible; and next, certain reptiles which are more or less commonly used as food, such as different kinds of turtles, and sometimes frogs. Some of the mollusks form important articles of food, more particularly oysters and clams. Some of the crustacea are very commonly used, such as lobsters, craw-fish, crabs, etc. Bees furnish honey, which is not an uncommon article of diet; but beyond this the class of insects contributes little or nothing to our food. Finally, certain animal products, particularly eggs and milk, are important aliments.

Meats.—With hardly any exceptions among the mammalia, the flesh of herbivorous animals is the only variety which is considered fit for food. All animals of this class are not considered edible. The flesh of the horse, of rats, and many others is excluded from the table in civilized countries.[1]

[1] In Paris, the attempt has frequently been made to introduce horse-flesh as an article of food—a movement which found favor to some extent among men of science. Among the advocates of this article may be mentioned, as the most prominent, the eminent naturalist and physiologist, Isidore Geoffrey Saint Hilaire. It has been found impossible, however, to establish a reputation for horse-flesh which would give it a place among the meats exposed publicly for sale; but it is pretty generally acknowledged that this article is consumed, in spite of the prejudice against it, under other names. (PAYEN, *op. cit.*, p. 59.)

Instinctively most persons prefer beef, as an habitual article of diet, to any other variety of meat. The experience of almost every one has taught that this article can be used more constantly than any other of its class. No meats become so distasteful from constant use as those which are considered as delicacies, when taken occasionally, such as venison or any variety of game. Any one can realize that it would be almost impossible to eat a considerable quantity of any kind of game daily for thirty or sixty days, yet there are many who, from choice, consume more or less fresh beef daily for months and years. "Beef-stock" is the basis of most soups and sauces, and is the main reliance of cooks in the preparation of what are generally termed made-dishes. Though of course there are individual exceptions, as there must be to any rule which may be laid down concerning the digestibility of different articles, beef is the most easily digested of any of the meats, and its influence upon the nutrition of the body is most favorable. All parts of the muscular system of the ox possess highly nutritive properties, but many are more esteemed than others, from superior flavor, tenderness, and perhaps facility of digestion. It is of course important that this animal, and others of the same class, should be of the proper age, well fed, and that the flesh be kept for a certain time before it is cooked. It is unnecessary to enter into details with regard to these points.

In China, it is well known that dogs, cats, and rats are exposed for sale in the public markets, and are extensively used as food. The ordinary prejudice against the carnivora is generally so far respected in that the avowed consumption of these animals seldom occurs; nevertheless many are used as food in the large cities of the world. Following the remarks on horse-flesh, Payen says: "They regard with as much care a similar prejudice, likewise very wide-spread, when they serve up to consumers, in the same establishments, *carnivora of a small feline species*, raised and nourished with great care, not, it is true, in view of such a destiny, but which none the less furnish at the occasion a kind of fur, and a nutritive meat of good quality, presenting, after cooking by the ordinary method, a very great analogy in appearance and taste with the flesh of the rabbit." (Ibid.)

Beef, as well as all kinds of meat, is composed of muscular tissue, a small quantity of blood, and interstitial fat. We have already seen that all nitrogenized principles contain a considerable proportion and a large variety of inorganic matters. In proximate composition, the different kinds of meat are quite similar, and the following analysis by Berzelius of the flesh of the ox may be taken as the type of the composition of most of them:

Immediate Composition of the Flesh of the Ox.

Water	77·17
Muscular fibre, vessels, and nerves	15·80
Tendonous tissue, reducible to gelatine by boiling	1·90
Albumen (analogous to the white of egg and the serum of the blood)	2·20
Substances soluble in water and not coagulable by boiling	1·05
Matters soluble in alcohol	1·80
Phosphate of lime	0·08
	100·00

According to Payen, among these soluble and insoluble substances are found lactic and inosic acids, creatine, creatinine, and organic nitrogenized matters, with alkaline salts, magnesian and calcareous. Meat contains, indeed, in 100 parts about 1·5 of soluble and insoluble salts, alkaline chlorides, and phosphates of potassa, of soda and magnesia. Meat contains beside, a small quantity of sulphur, which is in part a constituent of albumen of different origin, animal and vegetable; sulphur is likewise an integral part of fibre, of the horny substance of the nails, of hair, etc. It is found neither in cellular tissue, tendons, fibrous tissue of bones, nor in the gelatine produced by a solution at 212° of all these tissues.

"To all these substances indicated by this analysis and which constitute meats, must be added a saccharine substance, inosite, analogous to lactose (sugar of milk) and the fatty substances contained in a special tissue (adipose tissue). These last substances exert on the quality of the meat a favorable influence in proportion as, without being in excess,

they are best distributed in the mass. Thus the best butchers' meat presents in many parts between the muscular fibres an interposition of fat, which gives them the appearance of a whitish marbling."[1]

Taking the above as the type of the composition of the meats, it is evident that enough variety is here presented to answer the purposes of nutrition. The carnivora habitually live upon meat as the sole article of food, and examples are not wanting in which life is sustained in the same way in the human subject.

The composition of meat is somewhat modified by cooking. Odorous and flavoring principles are developed, which render it more agreeable, and the inter-muscular areolar tissue is softened, by which it is rendered somewhat more digestible. The following analyses were made by Payen of beef-steaks, about 1⅙ in. thick, cut from the tenderloin, exempt apparently from adipose tissue.[2]

Composition of Cooked Beef-steaks.

100 parts gave by analysis the following quantities of water, carbon, nitrogen, of fatty and mineral substances:

Water.	Carbon.	Nitrogen.	Fatty Matters.	Mineral Substances.
69·89	16·76	3·528	5·19	1·05

Immediate Composition.	*Cooked Meat.*	*Dry Substance.*
Water	69·89	0·00
Nitrogenized matters	22·93	76·18
Fatty substances	5·19	17·25
Mineral substances	1·05	3·50
Non-nitrogenized substances, sulphur, and loss	1·04 (0·94 ?)	3·07
	100·00	100·00

The composition of other varieties of meat being so much like that of beef, does not demand special consideration.

[1] PAYEN, *op. cit.*, p. 67.

[2] *Op. cit.*, p. 92.

In the admirable work of Payen, one of the most complete and exhaustive treatises on alimentary substances in any language, we find (page 71) a quotation from remarks made by Chevreul in a discussion at the Imperial and Central So-

The preparation of meat by cooking, and the methods which are employed for its preservation are important, and will be taken up hereafter. A point in this connection which has particular physiological and therapeutical interest is the preparation of soups and animal essences.

Mutton ranks next to beef as an agreeable and nutritive meat. Nearly all parts of the muscular system of the sheep are habitually used as food. It is difficult to establish any great difference in its nutritive properties from beef; but if taken constantly, without any variation, it is more apt to become distasteful—a fact which is important, as showing that it is hardly capable of supplying indefinitely that variety of alimentary matter which is so universally demanded. The flesh of the ram is coarse and of rather a disagreeable flavor; but the same may be said of many male animals that have not been castrated. The flesh of the goat is somewhat similar to mutton, but is less esteemed..

Next to mutton may be placed pork. This kind of meat is, perhaps, most frequently used after it has been preserved by salting or smoking; but it is often used fresh, and if thoroughly and properly cooked, it is an agreeable and nutritious article. The palate will not tolerate fresh pork as constantly as cured ham, bacon, shoulders, etc. It is to be remembered that cured pork occasionally contains the trichina spiralis, and when taken into the stomach un-

ciety of Agriculture of France, on the means of increasing the production of cattle. Chevreul gives the precedence, as a reparative meat, to beef, and takes, for purposes of comparison, as an example of beef of the first quality, an ox, from seven to nine years old, which, after having been worked at the ordinary labor of beasts of that kind, was fattened before being given to the butcher. He expresses the opinion that the meat of animals of mature age, exposed to the fresh air, and in an absolutely normal condition, is better than that of "precocious" animals, or those that have been fattened with abnormal rapidity. This is an important point to consider in the selection of all kinds of meat. A considerable amount of fat, especially interstitial fat, is desirable, as it renders the meat more tender; but aside from this, it is safe to assume that the highest physiological condition of the animal imparts to the flesh the most desirable properties as an article of food.

cooked these parasites find their way into the muscles, producing serious disease, and sometimes death. Since the disease called trichiniasis, as it occurs in the human subject, was first described by Professor Zenker, of Dresden, it has been frequently observed and carefully studied by pathologists. Pork that is thus tainted is called measly. The vitality of the parasite is destroyed by thorough cooking.[1]

The flesh of various non-domesticated animals is esteemed highly as food. In some parts of this country, buffalo-meat is largely used. This is somewhat coarser and of a more decided flavor than beef, but does not differ in its physiological properties. Venison is a meat very highly esteemed. This resembles mutton, but, as a constant article of diet, is by no means as agreeable. The flesh of the wild boar is used as food in many European countries. It is darker and more highly flavored than ordinary pork, and is generally regarded as a delicacy. In this country the raccoon (*Procyon lotor*), the woodchuck (*Arctomys monax*), and the opossum (*Didelphis Virginiana*) are occasionally eaten. These can hardly be ranked among the delicate varieties of game. They are not, however, unpalatable, but are excessively fat. Among the rodentia, we have the hare, most abundant in Great Britain, the rabbit, and the squirrel, which are very commonly used as food. Their meat is well-flavored and nutritious. The English hare is very highly esteemed.

The flesh of many animals is consumed before it arrives at maturity, as veal, lamb, sucking pig, etc. As a rule, this kind of meat is whiter, softer, and less nutritious than that of the adult animal, and develops in cooking less of that aromatic principle which adds so much to the agreeable flavor of meats. An exception may be made in the case of lamb, which is sufficiently high-flavored, and is rather more tender

[1] For an account of microscopic examinations of the muscles of a patient who suffered from this disease, and examinations of the meat by which it was produced, see DALTON, *Observations on Trichina Spiralis.—Transactions of the New York Academy of Medicine*, 1864, vol. iii.

and delicate than mutton, though as a constant article of diet it is not so useful. In the preparation of young meats, it is necessary to carry the temperature quite high and cook very thoroughly to develop an agreeable flavor, and it is especially necessary to have the surface well browned in order to produce the agreeable aroma which is characteristic of roast veal, pig, or lamb.

Domesticated and non-domesticated animals belonging to the class of birds constitute important and highly nutritive articles of diet. They are also useful in furnishing that variety of food which is so necessary to proper nutrition. Of the domestic birds, those most esteemed are the common fowl and the turkey. These should be thoroughly cooked in order to develop to the highest degree their characteristic flavor. The dark-meated domestic birds, the duck and goose, are quite commonly used as food. With the exception of the fowl, which is very delicate and well-flavored when young, all domestic birds are most savory and nutritious when they have arrived at maturity; though after that time age renders the meat tough and indigestible.

This continent presents a great variety of what are known as game-birds. Those most esteemed are the partridge, the quail, and the young prairie-chicken, which have white meat; and the wild goose, swan, duck in many varieties, plover, woodcock, snipe, and birds of this class. The well-grown but immature white-meated birds are very highly esteemed. The others should be young but full grown.[1]

As far as proximate composition and nutritive properties are concerned, the flesh of birds does not present any great differences from that of the mammalia. It is to be remarked, however, that the muscular tissue is never marbled by inter-

[1] Prairie-hens, called in this country, grouse, are very abundant in the Western States. When young, the breast and wings are white, but these parts become dark when they arrive at maturity. Except when very young, these birds are not so highly esteemed as other varieties of game. The delicious and high-flavored English pheasant is almost unknown in this country.

stitial deposits of fat. Poultry, as a rule, is easily digested and palatable, when properly prepared; but the game-birds, like all other kinds of game, are very decidedly flavored and become distasteful if used as food too constantly. The young white-meated birds form very appropriate articles of diet for persons convalescing from acute diseases.

Animal Viscera, etc.—Although the muscular substance constitutes the most important parts of animals used as food, some of the viscera and other parts are occasionally eaten. The external parts are the feet of pigs and calves and the skin of the calf's head, which are reduced to a gelatinous consistence by cooking. They seem to be easily disposed of by the digestive organs, but are not very nutritious. The pancreas and thymus of the calf (sweet-breads), the kidneys of the calf and sheep, the liver of the calf, of the pig, and of birds, the stomach of the ruminants (tripe), the gizzard, heart, brains, and tongue, all contain organic alimentary principles, nitrogenized and non-nitrogenized, and may be used as occasional articles of diet, but cannot permanently take the place of the muscular tissue.[1] It is a curious physiological fact that blood, the fluid which contains materials for the nutrition of all parts of the animal, does not appear to be a nutritious alimentary substance. Payen ascertained this fact, which the universal distaste for blood as an article of food would lead us to suspect, by experiments on pigs.[2]

[1] The celebrated *pâtés de foie gras* are made of the livers of geese, which are made to undergo hypertrophy and excessive fatty degeneration by confining the animals at a high temperature in a small cage, and stuffing them with food. The *pâtés de Strasbourg* are made of these livers, prepared with truffles and other articles. They are excessively rich, and are ordinarily considered difficult of digestion.

[2] *Op. cit.*, p. 129.

The substance of the bones does not enter, to any considerable extent, into the diet of the human subject, as it does in the carnivorous animals. The experiments of Magendie, detailed in the report of the "Gelatine Commission" (*Comptes Rendus*, Paris, 1841, tome xiii., p. 254), showed that dogs can live indefinitely on a diet composed exclusively of uncooked bones.

Animal Products used as Food—Eggs.—The eggs of various birds are frequently used as food, but those of the common fowl are by far the most esteemed. They contain, necessarily, all the principles which are demanded in the development of the chick, and are exceedingly nutritious. They are taken sometimes raw, but most frequently cooked, and in a great variety of forms which it would be out of place even to enumerate. The white of egg uncooked, or imperfectly coagulated, is ordinarily more digestible than when it has been rendered solid by prolonged boiling.

It is only necessary to refer to the composition of eggs to appreciate their nutritive value. According to Payen, the egg contains "nitrogenized substances (membranes, albumen, vitelline, *extract of meat*, yellow coloring matter); fatty matters (margarine, oleine, cholesterine, etc., margaric, oleic, and phospho-glyceric acids); a saccharine matter, sulphur, phosphorus, and mineral salts; phosphates of lime and magnesia, chlorides of sodium and potassium, carbonate of soda."[1] In addition, the important principle, iron, is always found in the ash after incineration. The white is composed chiefly of albumen with inorganic salts; and the yolk, of vitelline, with a large quantity of oil in the condition of an emulsion.

Milk.—At certain periods of life milk is the sole article of food, and it must be regarded as at all times one of the most nutritious and important of the animal products, being used largely in its natural form, and furnishing butter and the numerous varieties of cheese which are so largely consumed. The composition of milk affords an explanation of its highly nutritive properties. It contains a large amount of nitrogenized material, composed in greatest part of caseine, but containing albumen, and another principle not very well determined, called lacto-proteine; fatty matter in abundance, composed of a variety of principles of this class (oleine,

[1] *Op. cit.*, p. 130.

margarine, butyrine, and one or two other unimportant varieties); sugar of milk; coloring matter, and finally, a great variety of inorganic salts, including a combination of iron.

Cows' milk, which is the variety most commonly used, has, according to Payen, the following composition:[1]

Composition of Cows' Milk.

Water		86·40
Nitrogenized substances (caseine, albumen, lacto-proteine, and matters soluble in alcohol)		4·30
Lactose (sugar of milk or lactine)		5·20
Butter (or fatty matters)		3·70
A trace of coloring and aromatic matters.		
Salts, slightly soluble	Phosphate of lime; " " magnesia; " " iron	0·25
Soluble salts	Chloride of sodium; " " potassium; Phosphate and lactate of soda	0·15
		100·00

The quality of milk is usually considered with reference to its reaction, specific gravity, and its proportion of fatty matter. When perfectly fresh it is neutral or sometimes slightly alkaline. In a short time it becomes faintly acid, and its acidity is increased by the transformation of a portion of its sugar into lactic acid, until this becomes sufficient to coagulate the caseine. It is then said to be soured, and separates into the curd and whey. In this state it is not unwholesome,

[1] *Op. cit.*, p. 139.

It is hardly necessary to describe fully the other varieties of milk which are used as food. The milk of the goat, ass, mare, reindeer, and sheep are sometimes used, and present certain differences from cows' milk. In general, the odorous principles are distinctive. Goats' milk contains much more butter and a little more caseine and sugar than cows' milk. Ewes' milk contains a large excess of caseine and butter, but is rather deficient in sugar. Asses' milk contains a relatively small proportion of caseine and butter, and a large proportion of sugar. Mares' milk contains a very large proportion of sugar (8·75 per hundred), a small proportion of caseine, and very little butter. Human milk contains less caseine and more sugar and butter than cows' milk. This will be more fully considered in the section devoted to secretion.

and to some persons is agreeable. Its specific gravity is about 1,030, though this is subject to considerable variations. The proportion of cream in milk of good quality is from ten to fifteen parts per hundred by volume. Ordinary milk hardly contains so much. Milk that contains more than fifteen per cent. of cream may be regarded as excessively rich. These indications may be easily obtained by allowing milk to stand for twenty-four hours in a graduated glass tube. These little instruments, called lactometers, are frequently used for testing the milk of wet-nurses. It has been found that the proportion of fatty matter in cows' milk is much greater toward the end of a milking than at first. In an observation by Quevenne, during the first part of the milking the proportion of cream was five per cent., during the middle period fifteen per cent., and during the last period twenty-one per cent.[1]

The diet of the animal has an important influence on the quality of the milk and butter. Almost every one is familiar with the peculiarly disagreeable flavor of these articles when the cows have had access to leeks or onions. Except when animals are fed in pastures of great richness, the best milk is obtained by feeding judiciously in the stable, taking care to give water at proper intervals, to clean the animals carefully, and to allow sufficient exercise, with opportunities for rubbing the hide, etc.

Cream, though of less specific gravity than milk, under certain conditions is much more nutritious. Added to other articles of food, it frequently corrects defective nutrition more effectually than cod-liver oil, or any article that may be exhibited for that end. It contains a large quantity of fat, and has a very delicate and delicious flavor.

Buttermilk, the residue in the manufacture of butter, contains all the constituents of milk except the fatty matters, and is frequently used as an article of diet, particularly

[1] In PAYEN, *op. cit.*, p. 145.

in rural districts. It is agreeable, easily digested, and contains a considerable amount of nutriment. It is frequently useful in therapeutics, when other nutritious articles are not well borne.

Butter.—The only variety of butter used as food is that made from cows' milk; from which it is extracted by mechanically breaking up the oil globules, and causing their fusion into a homogeneous mass. It usually contains about one-sixth of its weight of buttermilk.[1] The best butter is made out of rich milk of good flavor, and contains only the flavoring principle of the cream, which is but slightly altered. In poor qualities of butter, either the milk has been inferior, or the fatty acids are freely developed. In this country butter is generally salted, but in many parts of Europe it is used fresh. It is an exceedingly important article of diet in all parts of the civilized world. Its important, and almost its sole alimentary principle, is fat, and it therefore demands no consideration beyond that which has already been given to this class of principles.

Cheese.—The coagulated nitrogenized constituents of milk, combined with a greater or less quantity of butter and inorganic salts, the more watery portions having been removed by pressure, constitute the important article of food called cheese. In this country, cheese is ordinarily so prepared and protected that it will keep for a length of time, and it becomes, in some instances, considerably improved by age. Its manufacture constitutes an important branch of industry in many sections, particularly those in which, from the quality of the pasture, the milk is unusually rich and well-flavored. In the ordinary form it is somewhat salted, and pressed into immense cakes or disks. The alterations

[1] PEREIRA, *Treatise on Food and Diet*, edited by Charles A. Lee, M. D. New York, 1843, p. 86.

which cheese undergoes are usually connected with the development of volatile principles from its fatty constituents. In addition, it is sometimes attacked by mould, by the larvæ of a peculiar kind of fly, and by the ordinary cheese-mite. The blue mould is thought by many not to injure the quality of cheese, and some even regard the development of skippers and mites as an improvement. Ordinary new cheese is a highly nutritious article, as is evident from its composition, but by many is not very easy of digestion. Old cheese, taken in small quantity toward the close of a repast, undoubtedly facilitates digestion by stimulating the secretion of the fluids, particularly the gastric juice.

The following is the composition of Cheshire cheese, which many of the American cheeses closely resemble:[1]

Composition of Cheshire Cheese.

Water	25·92
Nitrogenized matters (representing 4·126 of nitrogen)	25·99
Fatty matters (representing 41·11 for the cheese desiccated)	26·34
Salts (by incineration)	4·16
Non-nitrogenized matters and loss	7·59
	100·00

The foreign cheeses which those made in the United States most nearly resemble are made in England; and although the real Cheshire, Stilton, and Cheddar cheeses are undoubtedly the best of their kind, they have been very successfully imitated in this country.

The French market abounds in delicious varieties of cheese, many of which are fresh and very different from the articles ordinarily used in this country. Their richness and excellence, as indeed the good qualities of all cheeses, depend upon the quantity and quality of their fatty constituents. The fresh Neufchâtel cheese contains 8 per cent. of nitrogenized matter, and 40 per cent. of butter.[2] Almost all of the

[1] PAYEN, *op. cit.*, p. 209.

[2] This variety of cheese is very successfully imitated in New Jersey, opposite the city of New York, and is frequently sold as the true imported article.

different varieties of cheese are made from the milk of the cow; but the celebrated Roquefort is made from ewes' milk, which, as we have seen, is excessively rich in butter.

There is no very great difference in the varieties of cheese as regards nutritive properties, except that some, particularly the fresh cheeses, are more easily digested than others. The different varieties are severally sought after on account of their peculiar flavor. Some of the imported cheeses, particularly the German, if we may judge from the odor, are eaten after putrefaction has considerably advanced; but, though taken in considerable quantity, they seem to produce no ill effects in those accustomed to their use.

Fishes, Reptiles, Mollusks, and Crustacea.—The varieties of fish consumed as food in different parts of the world are innumerable. Many, such as the cod, mackerel, salmon, and certain varieties found in the great interior lakes of North America, are taken in immense quantities at particular seasons, and are preserved for use, either by salting, smoking, pickling, or drying. The flesh treated in this way is capable of nourishing the body only when combined with other articles, as the processes for its preservation, particularly salting, diminish its nutritive value, which is always considerably below that of meat. As an article of diet it is nevertheless important in contributing to the necessary variety in the nutritive principles. Though ordinarily but an accessory article of food, fish may constitute the important animal element; and there are localities where the inhabitants subsist almost entirely upon it, and are well nourished.

The muscular tissue of fish presents the same constituents as that of the higher classes of animals, but the proportion of solid materials is smaller. The roe (or ovaries), milt (or testicles), and swimming-bladder (or sounds), are sometimes used as food, and in some varieties of fish, as the shad and cod, are highly esteemed.

We will not attempt to even enumerate the varieties of

fish which are used in alimentation, or their differences in composition, etc. Suffice it to say, that a great number are ranked among the most delicious articles of food, and the skill of the cook is taxed to the utmost to prepare them for the table. Almost all kinds of fish are easy of digestion, as every one can bear witness from personal experience, except perhaps those which abound in oily matters, as salmon, eels, etc. Fish, to be eaten in perfection, should be taken at the time of full development of the generative organs, but not just before spawning, nor immediately after. The male, or soft-roed fish, is considered superior to the female. It is desirable always to eat fish as soon as possible after they are taken from the water.

The food of fish has an undoubted influence on their quality. It is now not unusual to confine them in ponds, where they may be fed and fattened till they grow to an enormous size, and become exquisitely delicate in flavor. By carefully protecting the spawn and the young fish they may be multiplied to a prodigious extent; for the eggs deposited by a single one in a season are numbered by thousands.

The flesh of fish resembles young meat in requiring thorough cooking to develop its flavor and render it easy of digestion.

In the class of reptiles, certain varieties of the turtle are the most important as articles of food. The large sea-turtle, known as the green turtle, weighing sometimes several hundred pounds, is used chiefly for soups. The flesh is sometimes cut into steaks and broiled, but is not very much esteemed in that form. A small animal of this class, the salt-water terrapin (*Emys palustris*), about six inches in length, is found in its perfection in brackish streams near certain parts of the Atlantic coast of the United States. This is considered one of the greatest delicacies peculiar to this country. It is highly nutritious, its flavor is very decided, and is to most persons very agreeable. Various of the small

fresh-water turtles are used for coarse soups, but are not much esteemed; except, perhaps, the gopher (*Testudo polyphemus*), which is used to some extent in the Southern States. The meat of turtles, when boiled, becomes white, and resembles veal in its general appearance.

The hind quarters of the larger varieties of the frog (*Rana esculenta* and *Rana catesbœana*) are sometimes cooked and eaten. Though it is a common impression that this article is chiefly used on the continent of Europe, it is probably as common in certain parts of this country as anywhere. The flesh is white, delicate, without much flavor, and but slightly nutritious.

In some of the wild and unsettled parts of the North American continent, snakes, particularly the rattlesnake (*Crotalus adamanteus*), are sometimes cooked and eaten, though not very frequently as a matter of choice.

Reptiles are not used as food in sufficient abundance to constitute important alimentary articles. The flesh is not very nutritious, and they must be considered simply as occasional articles of luxury.

The most important article of food belonging to the class of mollusks is the oyster. In addition there are the different varieties of clams—the salt-water clams being most esteemed—mussels, scallops, and a kind of snail called the *escargot.* The oyster in this country is an important article of diet, but the other mollusks are little used. Clams are chiefly used for soups. The flavor is agreeable, but the clams themselves are not generally much esteemed. Mussels, scallops, etc., are not much used as articles of luxury. Snails are consumed in France, but are used very little elsewhere.

The oyster in its greatest perfection exists in artificial beds along certain parts of the sea-coast of the United States. Statistics are wanting to show the extent to which oysters are consumed in the large seaport cities, but the quantity is enormous, to say nothing of those which are transported to the interior in kegs and cans. The best American oysters

are large enough to be cooked in a variety of ways, and their flavor when developed by cooking is superior to that of any in the world. They are frequently taken raw, when the small, firm, and salt oysters are most esteemed. Taken this way they compare favorably with the best European oysters; but have, perhaps, hardly the delicacy of flavor of the celebrated Ostend oysters.[1] Aside from peculiarities in different individuals with regard to the digestibility of particular articles, the oyster must be considered as highly nutritious and easily digested. It is acted upon by the digestive fluids more easily in the raw state than when cooked, even in the simplest manner. Proximate analyses of the oyster show a considerable quantity of organic nitrogenized matter, fat, and the inorganic salts. The proportion of solid matter is about five per cent.[2]

The liquor contained in the oyster-shell is also used, especially in cooking. It is impregnated with the flavor of the oyster, and contains a small quantity of nitrogenized and non-nitrogenized matter.

Many varieties of the crustacea are used as food; but they are important simply as articles of luxury, and as contributing to the necessary variety in the diet. These are generally spoken of as shell-fish, a name which is sometimes understood to include the mollusks. The most important articles of this class are lobsters, crabs, and shrimps. As a general rule, the flesh of the crustacea, though reputed to be quite nutritive, is difficult of digestion. In this country the ordinary lobster, and the crab just after it has shed its shell (the soft-shelled crab), are most highly esteemed.

[1] In Europe, several dozens of oysters are frequently eaten as a preparation to the more solid portions of a dinner; and when taken at other times, they are eaten by fifties and hundreds. In this country the oysters are so large that a dozen is considered a very fair allowance at any time.

[2] Payen (*op. cit.*, p. 221) gives the proximate composition of the French oyster, which probably does not differ much from other varieties except in size and flavor. The proportion of nitrogenized matter is about 14 parts per 100.

Preparation of Animal Articles of Food.

The preparation of food by cooking is designed to disintegrate its tissue, to develop flavors which will be agreeable to the taste and stimulate the secretion of the digestive fluids, and to prepare the alimentary principles so that they may be readily separated, liquefied, and finally absorbed. Many of the culinary processes accomplish these ends, but others are eminently unphysiological. Fortunately the latter, as the rule, do not render the food more agreeable to the palate.

One of the most important questions, in a chemico-physiological point of view, connected with the preparation of animal food, is with regard to the principles which are extracted from the various meats by prolonged boiling in water: for this is the mode of cooking which is frequently employed in hospitals and other institutions where it is desirable to present in the articles of diet an exact amount of nutritive material. This important subject has been investigated by the many eminent physiologists and physiological chemists, among whom may be mentioned as most conspicuous, Magendie, Chevreul, Liebig, and Payen.

By subjecting meat to prolonged and gentle ebullition in water, certain principles are volatilized and given off. These are ammonia in small quantity, an odorous principle peculiar to the kind of meat used, and certain volatile acid principles. Certain of the constituents of the meat may be dissolved by maceration in cold water, and quite a number of organic principles are dissolved by boiling. While it must be acknowledged that the concentrated animal broths present a considerable amount of nutritive material in a condition in which it is very easily digested, chemical analysis shows such a small proportion of solid matter that we are surprised that they possess so much nutritive power. Soup ordinarily contains a small quantity of gelatine, formed by a transformation and solution of some of the organic matter of the bones and the fibrous tissue, creatine, an organic nitrogenized mat-

ter formerly called osmazome, and numerous inorganic salts. The proportion of solid matter in soups is ordinarily from nine to ten parts per thousand. Coagulated albumen, a portion of the fat, and certain inorganic salts are removed in the scum. The boiled meat contains musculine, somewhat hardened and corrugated, coagulated albumen, fat, and inorganic salts. In the preparation of the different soups, various vegetables are commonly used, which add to the flavor and supply a certain quantity of nutritive matter.

The following formula, the result of numerous experiments, is now adopted for the preparation of soup for the hospitals and civil charitable institutions of Paris.[1]

Formula for making Soup.

	For 20 gal. of *bouillon.*
Water..................................	20 gal. (75 lit.)
Meat, weighed with the bones..............	68 lb. 10 oz. (31·245 grammes.)
Vegetables..............................	13 lb. 10 oz. (6·240 do.)
Salt....................................	1 lb. 12¾ oz. (0·840 do.)
Burnt onions (baked in an oven until desiccated)	7¾ oz. (0.220 do.)

The capacity of the kettles used should never exceed twenty gallons, as in larger vessels the pressure on the lower strata of the liquid causes the temperature to rise too high, and the aroma is thereby in part destroyed. The meat should be cut off from the bones and tied with strong cords into packages of nine or ten pounds each. The bones should be broken up and placed in the bottom of the kettle. The packages of meat should then be placed upon a grating or perforated false bottom, above the bones. Twenty gallons of cold water are then poured in, the whole is raised to the boiling point, and the scum is removed as it forms. It is kept gently boiling for two hours, during which time it is constantly skimmed. Between the first and second hour, when the skimming is nearly completed, the vegetables with

[1] PAYEN, *op. cit.*, p. 101. The weights and measures have been reduced from the French to the English standard.

the burnt onions are introduced enclosed in a net-bag. A gentle ebullition is then maintained for four or five hours. The fire is then extinguished, and after about an hour the vegetables, the meat, and the *bouillon* are taken out. When the latter is to be used, the congealed fat is taken from the top, and the *bouillon* is mixed with about the same quantity of water and heated to make the soup.

The simplest and most rational mode of cooking meats is by roasting or broiling, both of these methods being essentially the same in their operation. In this way none of the nutrient principles are lost, and the flavor peculiar to each variety of meat is most effectually developed and preserved. These operations should be so conducted that the most superficial portions of the meat are suddenly exposed to a temperature of from 212° to 270° Fahr.; while in the interior the temperature ranges from 125° to 150°. In this way the external parts are corrugated and hardened, so as to retain all of the juices, which are set free to a considerable extent by the more moderate heat in the interior. The nutritive principles of cooked meats seem to be more readily assimilated when the red coloring matters are not thoroughly coagulated. The art in broiling or roasting depends upon an observance of these cardinal principles. These rules are specially applicable to the fully-developed meats and to the dark-meated birds. Young meats, such as veal or lamb, and the white-meated birds, require a higher temperature throughout, and a more thorough cooking.

Many meats are well prepared by boiling, when the object is to cook thoroughly and render the meat tender, but to extract as little of the juices as possible. For this purpose salt is generally added to the water at first. The meats should be placed in cold water and boiled over a sharp fire. If put immediately into boiling water, the tissue becomes toughened. In stewing, meats are rendered tender and the juices are extracted but are preserved in the gravy. In baking, the interior of the meat is subjected to a higher tem-

perature than is desirable, which has rather an unfavorable influence on its flavor and digestibility.

All who have investigated the physiological relations of cooking declare that frying is the most objectionable mode of preparation of meat. The temperature to which the meat is exposed in this process is very high, and the flavor and nutritive properties are thereby greatly impaired. Meats prepared in this way should be coated with crumbs or batter, which prevents, to some extent, the penetration of the hot fat.

It is unnecessary to discuss the methods employed in the preparation of the mollusks, crustacea, etc., which are to be regarded generally as articles of luxury; and a consideration of condiments, spices, and various vegetable articles used in refined cooking would be out of place, as they refer chiefly to the taste, and have no direct bearing on nutrition. Some articles are most palatable when cooked in the simplest way; but others are improved by the addition of flavoring principles, among the most remarkable of which is the world-renowned truffle, which, when judiciously used, imparts its delicious perfume to the meat, but takes away nothing of its peculiar flavor. The truffle is especially esteemed in the cooking of white-meated birds.

When we come to consider specially the different digestive processes, it will be seen that proper preparation of food greatly facilitates its digestion and assimilation. In the hygiene of armies, of charitable institutions and hospitals, and of individuals, there are few things more important than an observance of the great physiological principles of the art of cooking.

Aliments derived from the Vegetable Kingdom.

We have seen that some of the most important alimentary principles are derived from the vegetable kingdom. Starch, and preparations which are composed chiefly of this principle, sugars, and the vegetable oils, have already

been considered with sufficient minuteness. It remains now to treat of the composition and properties of some of the more important vegetables and the articles which are made from them, particularly the different kinds of bread. The various fruits, many of which are mere articles of luxury, demand only a passing mention.

Cereal Grains.—The cereal grains commonly used as food are wheat, Indian corn, rye, buckwheat, oats, barley, and rice. Wheat, corn, rye, buckwheat, and oats, are generally ground, freed from the bran, and the flour or meal is made into bread, cakes, gruel, or porridge. Barley, rice, and green corn, are frequently taken after simple boiling. The articles made from these different grains possess different nutritive properties, though they are all more or less important. Wheaten flour is the only preparation of the cereals capable of making that most important of all alimentary articles, good bread. The mechanical properties of moist gluten enable us to form from flour, by the process known as raising, a light, porous bread, which is entirely different from articles manufactured from meal of any other kind.

Wheat must be considered as by far the most nutritious of all grains. It contains, after desiccation, from fifty to seventy-five per cent. of starch, from ten to twenty per cent. of nitrogenized matters, about two per cent. of fatty matter, six to ten per cent. of dextrine and sugar, two to three per cent. of inorganic salts, and a certain quantity of cellulose. It is distinguished from all other grains by its large proportion of glutine. When we come to consider the composition and properties of bread, we will see the great importance of this principle.

Corn is distinguished from other grains by its large proportion of oily matter (between eight and ten per cent.), by a peculiar odorous principle, and by its small proportion of nitrogenized matter. It contains a larger proportion of indigestible vegetable tissue than any of the grains,

excepting oats. In this country, some of the earlier and more tender varieties, commonly called sweet corn, are used as a fresh vegetable, being simply boiled or roasted; and in this form are nutritious, and, as a rule, easily digestible. Corn-meal is used in the preparation of what is called corn-bread and various cakes and puddings. Corn-bread is a very common article of diet in the Southern States. Articles made from corn-meal cannot take the place of wheaten bread; and when not carefully prepared are apt to cause diarrhœa in persons not accustomed to their use. On account of the proportion of oil, corn and corn-meal are very useful in fattening animals, particularly swine. In the large cities of the United States and in Europe, corn-meal is not a very important article of diet.

Rye-meal is sometimes used to make bread. The bread is more compact than wheat-bread, has a peculiar taste, a brown color, and is less nutritious. In many parts of the world rye is used instead of wheat on account of its cheapness; and in this country it is sometimes used with the idea that it is more digestible and nutritious. It makes very good bread, but cannot take the place of wheat. In composition rye is distinguished from wheat in containing less nitrogenized matter and a larger proportion of dextrine and sugar.

Buckwheat does not differ materially from rye, except that it contains very much less dextrine and sugar. In this country it is seldom used except in making baked cakes, which are here very highly esteemed. In some of the poorer sections of the old world, buckwheat mixed with wheat-flour is used in making bread; but this is only on account of its cheapness, for it does not improve the flavor of bread, and is much inferior to wheat in nutritive properties.

Oat-meal is not an important article of diet in this country, though it is largely used in Scotland and some of the northern parts of England. It contains a large proportion of oil, over five per cent., with peculiar aromatic principles. It is very much used as food for horses; and for this pur-

pose no other grain can take its place. The oat-cakes, which are so common in Scotland, are apt to produce diarrhœa in persons not accustomed to their use.

Barley is not a very important article of diet. In composition it resembles rye. Barley-water, a mucilaginous drink made by boiling barley, contains gum and a small proportion of nutritive material, and is often used in therapeutics as an agreeable demulcent drink. Malt, which is so largely used in brewing, is produced from barley which has been made to germinate by heat and moisture. It is in this process that the ferment called diastase is produced.

Rice is produced in abundance in low, swampy lands in certain parts of the United States, particularly South Carolina. Millions of people in Eastern countries are said to subsist almost exclusively on this article. For this reason it is regarded by many as highly nutritive, though analysis shows that it contains a comparatively small proportion of nitrogenized matter, its chief ingredient being starch. The proportion of starch in rice is nearly ninety per cent. It is probable that the nutritive properties of rice have been much exaggerated. When it constitutes the greater part of the food, it is consumed in enormous quantities; and in those countries in which the inhabitants are said to live exclusively upon it, other articles which contain an abundance of fatty and nitrogenized principles are mixed with it. Although rice is considerably used in civilized countries, it is not a very important article of diet. It is used chiefly in puddings, delicate cakes, and sometimes in soups, or simply boiled.

Bread.

There is probably no animal nor vegetable article of food that presents so admirable a combination of alimentary principles as that which is appropriately denominated "the staff of life." This fact is corroborated by its universal acceptance as the prime article of diet in all civilized countries. It is an article which never becomes distasteful from monot-

ony, demonstrating in this how completely it meets the wants of the system. A comparison of the composition and properties of the different cereal grains has made it evident that in the manufacture of bread nothing can take the place of the alimentary principles contained in wheat. Of the different varieties of wheat, that which is known as the hard grain makes the best and most nutritious bread. In some of the poorer sections of the old world the quality of the bread is impaired by the mixture of rye, buckwheat, etc., with wheaten flour; but in this country this is never done, and, as the rule, the quality of bread depends entirely on the skill employed in its manufacture. It is evident that there are few questions connected with alimentation which have greater importance than the scientific principles involved in the making of bread. In this particular we may safely follow the French, as they undoubtedly make the best bread in the world.[1]

Of course, the starting-point in the manufacture of good bread is to have good flour, in the production of which this country is unsurpassed. The first operation in making bread is to mix with one hundred parts of flour from fifty to sixty parts by weight of water, adding a little salt, and fresh yeast in the proportion of about half an ounce to ten pounds. The mass is then thoroughly kneaded until it forms an elastic, homogeneous dough. Some bakers are in the habit of adding to the dough a little potato and alum; but these must be regarded as adulterations, although the potato is not injurious. When the dough has been thoroughly kneaded, the gluten is so mixed with the other ingredients and is so tenacious and elastic, that the surface will not be broken by the gas which is to be evolved in its interior. It is then divided into loaves, and set aside for from six to eight hours, at a temperature of from 80° to 100° Fahr., to "rise."

[1] The essential parts of the process of making bread are taken from the admirable work of Payen, which has already been so frequently alluded to in connection with alimentation.

The process of raising or fermentation, called sometimes panification, is characterized by several important changes in the composition of the flour. These changes may take place spontaneously from decomposition of the gluten and its action as a ferment, or they may be induced, as is commonly the case, by yeast, or by gluten already in process of decomposition, called leaven. The process of panification involves three kinds of action, viz., the alcoholic, the acetic, and the lactic acid fermentation. The alcoholic fermentation is due to a decomposition of the small proportion of sugar which the dough contains into carbonic acid and alcohol. But this is not the only source of these principles. A certain quantity of the starch is converted first into dextrine and afterward into sugar, which finally undergoes alcoholic fermentation. The evolution of gas in this way raises the dough, and forms little cavities in the bread, which give it its peculiar porous character; the elasticity and tenacity of the gluten allowing the dough to swell, and retaining the gas in its interior. As gluten is particularly abundant in wheaten flour, it is from this only that good light bread can be made.

When the dough has been sufficiently raised, it is put into the oven and baked. The application of heat at first increases the development of gas, but when the temperature is raised to 212°, the process of fermentation is arrested; and afterward the baking simply cooks and fixes the dough in its expanded condition. The alcohol generated in the process of raising is volatilized and driven off in the baking.[1] The superficial portions of the loaf are exposed to a temperature of about 375°, by which they are hardened, forming the crust, and a portion of the starch before unaltered is transformed into dextrine. It is well known that the crust of bread contains

[1] A number of years ago a patent was taken out in England for a process for collecting the alcohol evolved in baking bread. The project succeeded as far as collecting the alcohol was concerned, but failed as a commercial operation. (PEREIRA, *Treatise on Food and Diet*, New York, 1843, p. 147.)

more soluble matter than the interior. The temperature of the interior is not raised much, if any, above 212°. The acidulous fermentation takes place to a limited extent even in good white bread; but this is apt to proceed further than is desirable if the dough be allowed to ferment too long. In that case the bread is sour and indigestible.

Brown bread may be made either of unbolted flour, or of flour to which a small quantity of bran has been added. A bread called bran-bread is made of an excess of bran with a small quantity of flour. The bread formerly issued to the French soldier (*pain de munition*) was made from flour with only 15 per cent. of its bran removed; unbolted flour containing about twenty per cent. The color of this kind of brown bread is due, not to the color of the bran, but to peculiarities in the process of panification. In the bran is contained a peculiar principle called *cerealine*, which is capable of becoming a very active ferment. The effect of its action is to change starch into dextrine, then into sugar, and finally into lactic acid. Its most important influence, however, is exerted upon the gluten. This it transforms into ammonia, a peculiar brown substance which gives the color to the bread, and a new ferment capable of transforming sugar into lactic acid. These changes may take place to some extent in bread which is inferior in quality from being allowed to ferment too long, so that the acidulous action predominates. Brown bread is not as light as bread of the best quality, and contains less gluten, a considerable quantity having undergone transformation into ammonia and brown coloring matter. It is not so easily digested, from the fact that it is less easily penetrated by the gastric juice. Very fresh bread, particularly if it be warm, is less easily digested than after it has been allowed to become "stale." In this state the process of mastication compresses it into pasty masses which are not easily penetrated by the digestive fluids; while bread eaten a few hours after baking is disintegrated by mastication, and absorbs the fluids of the mouth in

large quantity. The importance of porosity in improving the digestibility of bread has been illustrated by experiments on animals. Dr. Hammond caused a dog, in which he had established a gastric fistula, to eat successively equal weights of vesiculated and compressed bread. The first was digested in two hours and fifteen minutes, and the latter, in three hours and thirty-five minutes.[1]

In the manufacture of good bread it is absolutely necessary to render it porous by the generation of gas in the dough before baking; but this may be effected without fermentation. Unfermented or aërated bread may be made by mixing carbonate of soda with the flour and adding hydrochloric acid in the water, or by using water charged with carbonic acid. The use of bread made in this way is simply a question of taste.

Flour simply mixed with water and baked, called in this form ship-bread, sea-biscuit, hard-tack, etc., will keep almost indefinitely. It requires thorough mastication, and is not so easily digested as ordinary bread, but apparently all the nutritive principles are preserved. The other forms of bread, rolls, muffins, etc., are simply articles of luxury, and do not differ much in their nutritive properties from ordinary bread. The various forms of cake are made of flour, with the addition of butter, lard, eggs, sugar, and sometimes dried fruits.

Although bread has been called the staff of life, it seems incapable by itself of supplying for an indefinite period all the nutritive demands of the human organism. The same may be said, however, of every single article of food, whether it belong to the animal or vegetable kingdom; for man requires a much greater variety of alimentary principles than the inferior animals. While it is possible that life might be barely sustained on bread and water, experience with regard to this diet in prisons and elsewhere has demonstrated that it is incapable of maintaining the body in full vigor. That this is

[1] HAMMOND, *Treatise on Hygiene*, Philadelphia, 1863, p. 519.

probably due to a deficiency in variety of alimentary principles is shown by Magendie's experiments on dogs:

"A dog eating *ad libitum* of white bread, made of pure wheat, and drinking at will ordinary water, does not live beyond fifty days; he dies at the end of that time, with all the signs of gradual exhaustion above noted.

"A dog eating exclusively of military brown bread (*de munition*) lives very well, and the health is not altered in any way."[1]

Brown bread is not perhaps absolutely so nutritive as white; but as it contains a certain quantity of the bran, it presents a greater variety of nutritive principles, and seems, from the above experiments, better calculated, as the single article of food, to meet the demands of the system.

The paste, which in Italy takes the place, to a great extent, of bread, in the form of macaroni, vermicelli, etc., is a highly nutritious preparation. The real Italian article is made of the hard wheat with only the outer covering removed, and contains a much greater proportion of gluten and oily matters than ordinary bread. It is made to assume its peculiar form by forcing the thick paste through perforated metallic plates. It is then dried and may be kept for any length of time. Presenting, as it does, a larger proportion of nitrogenized and fatty matters, it is more nutritious than bread. Payen estimates the nutritive value of 100 parts as equal to 151·5 parts of white bread.[2]

Leguminous Roots, Leaves, Seeds, etc.

The remaining vegetable articles of food do not demand extended consideration, as the alimentary principles which they contain are little different from those already described. They are highly useful, however, as furnishing that variety of diet, the necessity of which cannot be too fully in-

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 504.

[2] *Op. cit.*, p. 294.

sisted upon; but as far as quantity and variety of essential alimentary principles are concerned, there is no one of them which is comparable to wheaten bread.

The ordinary potato is by far the most important of the leguminous roots. It undoubtedly forms a larger part of our vegetable food than any other article except wheat; and of all vegetables it is the one that becomes least distasteful from continued use. In Ireland, the potato forms the greatest part of the diet of the poorer classes, but those who live almost exclusively upon it are not well nourished. It is generally taken after the starch-granules have been disintegrated and its general structure softened by cooking; but in a raw state it has been found very useful in scurvy, or where there is a scorbutic tendency, particularly in armies. A study of the proximate composition of the potato shows that it cannot of itself be capable of maintaining the organism in full vigor, on account of its great deficiency in nitrogenized and fatty materials:

Proximate Composition of the Potato.[1]

Water	66·875
Starch and amylaceous fibre	30·469
Albumen	0·503
Gluten	0·055
Fat	0·056
Gum	0·020
Asparagin	0·063
Extractive	0·921
Chloride of potassium	0·176
Silicate, phosphate, and citrate of iron, manganese, alumina, soda, potash, and lime (of these, potash and citric acid are the prevailing ingredients)	0·815
Free citric acid	0·047
	100·000

The sweet potato, so largely used in the United States, contains more water, and about half the proportion of starch

[1] PEREIRA, *Treatise on Food and Diet*, New York, 1843, p. 180.

contained in the ordinary potato, and from four to five per cent. of sugar.

Some other articles belonging to the class of leguminous roots, the beet-root for example, contain a large proportion of sugar, but ordinarily they are deficient in starch[1] as compared with the potato, and present but a small quantity of nitrogenized matter. Many, like the parsnip, salsify, carrots, etc., contain a certain amount of volatile oil and peculiar flavoring matter. Onions and garlics are remarkable for the presence of a large quantity of volatile oil. These articles are specially craved when the system is suffering from a deficiency of vegetable food, and are very useful in scurvy.

The young and tender shoots of asparagus are highly prized for their exquisite flavor. The volatile principle of this vegetable is eliminated by the kidneys, giving a very peculiar odor to the urine.

Many green leaves and leaf-stalks, such as cabbage, cauliflower, lettuce, celery, chiccory, cresses, etc., are used as food, but chiefly as articles of luxury. They contain a large proportion of water, and little or no starch. *Sauer-kraut*, which is so commonly used in Germany, is made by packing cut cabbage with salt under a heavy pressure, and allowing it to remain for several weeks until it has undergone the acetic acid fermentation. It is then stewed and eaten with meats.

The leguminous seeds possess a certain degree of importance as alimentary substances. Those most commonly used are the different varieties of beans and peas. They contain a large proportion of starchy matter, and a considerable quantity of vegetable caseine. When dried they constitute an important part of many army-rations. They must be considered as highly nutritious, though inferior to most of the cereal grains, notwithstanding that they contain a large

[1] For a list of vegetables containing little or no starch, see p. 57.

proportion of nitrogenized matter. They contain a very small proportion of the phosphates.

The ripe fruits are characterized by the presence of large quantities of sugar, mallic and citric acid and their combinations, pectine or vegetable jelly, and by the absence of starch. They are used as articles of luxury and contribute somewhat to the variety in diet, but they are not very important as alimentary substances. The various melons are particularly grateful and refreshing, but they contain a very small proportion of solid or nutritive matters.

Condiments and Flavoring Articles.

The refinements of modern cookery involve the use of numerous articles which cannot be classed as alimentary principles. Pepper, capsicum, vinegar, mustard, spices, and articles of this class, which are so commonly used, with the various compound sauces, have no decided influence on nutrition, except in so far as they promote the secretion of the digestive fluids. Common salt, however, as we have already seen, is very important, and has already been considered under the head of inorganic alimentary principles. The various flavoring seeds and leaves, truffles, mushrooms, etc., have no physiological importance except as rendering articles of food more palatable.

CHAPTER IV.

DRINKS.—QUANTITY AND QUALITY OF FOOD.

Water—Alcohol—Distilled liquors—Wines, malt liquors, etc.—Coffee—Tea—Chocolate—Quantity and variety of food necessary to nutrition—Necessity of a varied diet.

Water.

WATER, one of the most important of the proximate principles of the organism, and found in every tissue and part without exception, is introduced with all kinds of food, and is the basis of all drinks. Its functions in the economy have already been fully considered. As a rule, it is taken in greater or less quantity in nearly a pure state. Although, as a drink, water should be colorless, odorless, and nearly tasteless, it always contains more or less of saline and other matters in solution, with a certain quantity of air. The air and gases may be evolved by boiling or removing the atmospheric pressure. Pure water (HO) does not exist in nature. Even rain-water always contains salts, and frequently a little ammonia and organic matter. The Croton water supplied to the city of New York, contains 4·16 grains of solid matter to the gallon.[1] The waters of the mineral springs, which are so abundant in parts of this country, are very rich in saline constituents, and generally contain a notable quantity of carbonic acid; but the consideration of their properties does not belong to physiology. Water charged with carbonic acid under pressure, called soda water, or in

[1] Dr. LEE, in PEREIRA, *on Food and Diet*, p. 43, note.

France *eau de Seltz*, is a very common drink, and its excellence depends on the thoroughness with which the gas has been washed and freed from impurities. Sea-water may be rendered fit for drinking by distillation and agitation with air. Apparatus for thus supplying pure water is generally found in well-appointed sea-going vessels.

The demand on the part of the system for water is regulated, to a certain extent, by the quantity discharged from the organism, and this is subject to great variations. The quantity taken as drink also depends very much on the constitution of the food as regards the water which enters into its composition.

Alcohol.

All distilled and fermented liquors and wines contain a greater or less proportion of alcohol. As these are so generally used as beverages, and as the effects of their excessive use are so serious, the influence of alcohol upon the organism has become one of the most important questions connected with alimentation. In the discussion of this subject it is not proposed to enter into the great moral questions involved, but to consider, from a purely physiological point of view, the immediate and remote influences of the various alcoholic beverages upon nutrition and the animal functions. Some alcoholic beverages influence the functions solely through the alcohol which they contain; while others, as beer and porter, with a comparatively small proportion of alcohol, contain a considerable quantity of solid matters which may act as alimentary principles.

Alcohol ($C_4H_6O_2$), from its composition, is to be classed with the non-nitrogenized principles, more especially the fats, in which the hydrogen and oxygen do not exist in the proportion to form water. We have seen that sugar and fat are essential to proper nutrition and undergo in the organism important changes. Alcohol is capable of being absorbed and taken into the blood; and it becomes a question of great

interest to determine whether it be consumed in the economy, or whether it be discharged unchanged by the various emunctories. Many volatile and other substances are known to be thus exhaled or discharged from the body. The volatile principle of the onion may be recognized in the expired air for some time after the article has been taken into the stomach. Various ingested matters are discharged unchanged in the urine. Common salt, when taken in excess, is thus removed. But all the ordinary nitrogenized and non-nitrogenized principles in the ingesta are consumed, undergo certain transformations in nutrition, and are never discharged, in health, in the form in which they entered.

Alcohol has long since been recognized in the expired air after it has been taken into the stomach; and late researches have confirmed the earlier observations with regard to its elimination in its original form, and have shown that after it has been taken in quantity, it exists in the blood and all the tissues and organs, particularly the liver and nervous system.[1] Lallemand, Perrin, and Duroy have noted the elimination of alcohol by the lungs, skin, and kidneys.[2] The experiments by which these results were arrived at are very satisfactory. They show that even when a very small quantity of alcohol is taken it may be detected in the blood and is eliminated for many hours, progressively diminishing in quantity from the period of its ingestion, until it is all removed or destroyed. In a man after taking "an ordinary quantity of alcoholic drink" (a little more than a quart of red wine containing

[1] It was formerly a question considerably discussed whether alcohol exists in the brain, or in the fluid found in the ventricles, in intoxicated persons. This was settled by Percy, who found alcohol in the brain, liver, and sometimes in the urine, in dogs poisoned with alcohol, and in men who had died after excessive drinking. In these experiments, the presence of alcohol was determined by distillation, the distilled substances being inflammable, and capable of dissolving camphor.—PERCY, *Prize Thesis. An Experimental Inquiry concerning the Presence of Alcohol in the Ventricles of the Brain, etc.*, London, 1839.

[2] LALLEMAND, PERRIN, et DUROY, *Du Rôle de l'Alcool et des Anesthésiques dans l'Organisme*, Paris, 1860.

ten per cent. of alcohol), "the lungs eliminated alcohol for eight hours, and the kidneys for fourteen hours."[1]

The question now arises whether the alcohol be eliminated in totality, or whether it be in part removed in this way, and in part destroyed in the system. This it is difficult to answer with positiveness. It has been shown that a certain amount of alcohol may be transformed into acetic acid in the stomach, but this quantity is insignificant, and the experiments of the observers above quoted show that it does not take place in the general system. The view that alcohol undergoes combustion or oxidation is based upon theoretical and not upon any experimental considerations; and the fact that this substance is always eliminated, even when taken in minute quantity, and that its elimination continues for a considerable time, gradually diminishing, render it probable that all that is taken into the body is removed. The practical difficulties in the way of collecting all the exhalations, especially those from the skin and lungs, are so great, that this cannot, as yet, be demonstrated experimentally.[2]

[1] *Op. cit.*, p. 121.

Percy detected alcohol in five ounces of urine taken from a man in a condition of intoxication, by first distilling over three drachms of a colorless liquid, subjecting this to a second distillation in which one drachm passed over, which was agitated in a test-tube with subcarbonate of potassa. He thus obtained a clear supernatant stratum, which dissolved camphor and burned with a blue flame (*op. cit.*, p. 105). There can be hardly any doubt but that the kidneys always eliminate a certain quantity of alcohol when this substance finds its way into the circulation.

[2] A recent English writer, Dr. Anstie, does not accept the observations of Lallemand, Perrin, and Duroy as showing that, in all probability, alcohol taken into the alimentary canal is eliminated as alcohol, and is removed in totality by the various emunctories. The experiments of Dr. Anstie are not on a very extended scale, and, as far as they go, rather support than controvert the opinion of the French observers. He found that even after small doses of alcohol had been taken, the presence of this substance could be determined in the urine and in the pulmonary and cutaneous exhalations. (*Stimulants and Narcotics*, Philadelphia, 1865, p. 358 *et seq.*) It must be remembered, however, that the total elimination by the lungs and skin of watery vapor, which is much less volatile than alcohol, is enormous, although, by the skin especially, its quantity in a lim-

In the present state of our knowledge, alcohol cannot be regarded as an aliment; but it is undoubtedly capable of profoundly affecting the nervous system, and, in its passage through the organism, has a decided influence on the process of nutrition.

Taken in moderate quantity, alcohol generally produces a certain amount of nervous exaltation, which passes off as it is eliminated. In some individuals the mental faculties are sharpened by alcohol, while in others they are blunted. There is nothing, indeed, more variable than the immediate effects of alcohol on different persons. In large doses the effects are the well-known phenomena of intoxication, delirium, more or less anæsthesia, coma, and sometimes, if the quantity be excessive, death. As the rule, the mental exaltation produced by alcohol is followed by reaction and depression, except in debilitated or exhausted conditions of the system, when the alcohol seems to supply a decided want.

The views of physiologists concerning the influence of a moderate quantity of alcohol on the nervous system are somewhat conflicting. That it may temporarily give tone and vigor to the system, when the energies are unusually taxed, cannot be doubted; but this effect is not produced in all individuals. The constant use of alcohol may create an apparent necessity for it, producing a condition of the system which must be regarded as pathological.

The immediate effects of the ingestion of a moderate quantity of alcohol, continued for a few days, are decided. It notably diminishes the exhalation of carbonic acid and the discharge of other excrementitious principles, particularly urea. These facts have long since been experimentally demonstrated;[1] but recently, very important observations

ited period is apparently small, and is estimated with great difficulty. It is by these avenues particularly that we should suppose that so volatile a principle as alcohol would be chiefly thrown off.

[1] The influence of alcohol on the exhalation of carbonic acid has already been considered (see vol. i., Respiration); and its effect on the quantity of urea discharged will be more fully treated of in connection with excretion.

have been made by Dr. Hammond, which bear more particularly on the influence of this agent on nutrition. It is well known that by carefully regulating the diet, exercise, etc., the weight of the body, in a healthy man, can be maintained for a time at a standard which may be taken as normal. Under these conditions the mind is clear, the appetite good, the food is relished, and every function appears to be in normal operation. Dr. Hammond—after a number of experiments in which he established, in his own person, the conditions which would maintain the weight at a fixed point, and having noted the exact quantities of the excretions and the exhalations from the lungs—took at breakfast, luncheon, and dinner four drachms of alcohol diluted with an equal quantity of water, and continued this for five days. The results we give in his own words:

"Thus, after the use of sixty drachms of alcohol in five days, my weight is seen to have increased from an average of 226·40 pounds to an average of 226·85 pounds, being ·45 of a pound difference. The carbonic acid and vapor of water in the expired air had respectively decreased 1,324·50 and 196·51 grains; the fæces, 1·22 ounces; the urine, 3·43 ounces; the urea, 87·19 grains; the chlorine, 37·59 grains; the phosphoric acid, 24·47 grains, and the sulphuric acid, 13·40 grains. The free acid and uric acid, especially the former, were so slightly affected as to render it probable that the alcohol had exercised no influence upon them."[1] During this time there was some disturbance of the general health. The pulse was increased in frequency, there was headache, and the mental faculties were not so clear as on the days when no alcohol was taken.

The second series of experiments was for the purpose of ascertaining the influence of alcohol when the body was losing weight from an insufficiency of food. It was found that by reducing the daily quantity of meat from sixteen to

[1] Hammond, *The Physiological Effects of Alcohol and Tobacco upon the Human System.—Physiological Memoirs*, Philadelphia, 1863, p. 48.

ten ounces, and the bread from eighteen to twelve ounces, the loss of weight was well marked. This diet was continued for five days, with the effect of reducing the weight from 226·73 to 225·34 pounds; a daily average loss of ·28 of a pound. At the end of the five days, twelve drachms of alcohol were taken daily, as before, and continued for five days. The decrease in weight was not only arrested, but there was an increase of ·03 of a pound daily. The quantity of food fully satisfied the appetite, and "all the functions of the body were performed with regularity;" while during the five days preceding the use of alcohol, there was unusual exhaustion after exertion, "and the desire for food was very much increased, and was never completely appeased by the quantity ingested."[1]

In a third series of experiments, an excess of food was taken. This increased the weight by an average of ·22 of a pound daily; there was constant headache, indisposition to exertion, loss of appetite, etc. For five days succeeding this, twelve drachms of alcohol were taken daily, with the effect of diminishing the quantities of excretions and exhalations, aggravating the unpleasant symptoms produced by the excess of food, and increasing the average gain in weight from ·22 to ·31 of a pound.

These experiments demonstrate the actual immediate influence of alcohol upon nutrition, under the conditions above given; for the observer was a young man, in perfect health, and not accustomed to the constant use of alcoholic beverages. The observations were apparently conducted with great exactness, and continued sufficiently long to afford definite results; of which the following are some of the most important:

The ingestion of a moderate quantity of alcohol retards the destructive assimilation of the tissues; for the diminution in the quantity of the excretions in the experiments of Hammond was too long continued to admit of the theory that the

[1] *Loc. cit.*

effete products were simply retained in the blood and not removed by the proper organs.

It is also demonstrated that when the system is so nourished that the weight is stationary, the moderate ingestion of alcohol, for a short time, will cause an increase in weight corresponding with the diminution in the quantity of the excretions; with, however, some disturbance of the general health and the mental faculties.

The loss of weight consequent upon insufficiency of food may be temporarily arrested and the unpleasant symptoms relieved by the use of alcohol in moderate quantity.

The gain in weight following over-ingestion of food is increased and the disturbance of the system aggravated by the use of alcohol.

If the observations showing the elimination of alcohol from the system be taken as conclusive, it is evident that this agent influences nutrition in its passage through the organism, and that its immediate effects are of a transitory nature. It cannot be considered as an alimentary principle, or as capable of supplying the place of articles which are actually assimilated. The proper amount of mental and physical exercise, tranquillity of the nervous system, and all circumstances which favor the vigorous nutrition and development of the organism physiologically increase, rather than diminish, the amount of the excretions, correspondingly increase the demand for food, and, if continued, are of permanent benefit. Alcohol, on the other hand, diminishes the activity of nutrition. If it be long continued, the assimilative powers of the system become so weakened that the proper quantity of food cannot be appropriated, and alcohol is craved to supply a self-engendered want. The organism may, in many instances, be restored to its physiological condition by discontinuing the use of alcohol; but it is generally some time before the nutritive powers become active, and alcohol, in the mean time, seems absolutely necessary to existence.

Under ordinary conditions, when the organism can be adequately supplied with food, alcohol is undoubtedly injurious. When the quantity of food is insufficient, alcohol may supply the want for a time, and temporarily restore the powers of the body; but the effects of its continued use, conjoined with insufficient nourishment, show that it cannot take the place of assimilable matter. These effects are too well known to the physician, particularly in hospital-practice, to need further comment.

Notwithstanding these undoubted physiological facts, alcohol, in some form, is used by almost every people on the face of the earth—civilized or savage. Whether this be in order to meet some want occasionally felt by and peculiar to the human organism is a question upon which physiologists have found it impossible to agree. That alcohol, at certain times, taken in moderation, soothes and tranquillizes the nervous system and relieves exhaustion dependent upon unusually severe mental or physical exertion, cannot be doubted. It is by far too material a view to take of existence, to suppose that the highest condition of man is that in which the functions, possessed in common with the lower animals, are most perfectly performed. Inasmuch as temporary insufficiency of food, great exhaustion of the nervous system, and various conditions in which alcohol seems to be useful, must of necessity often occur, it is hardly proper that this agent should be utterly condemned; but it is the article, *par excellence*, which is liable to abuse, and the effects of which on the mind and body, when taken constantly in excess, are most serious.

Although alcohol imparts a genial warmth when the system is suffering from excessive cold, it is not proven that it enables men to endure a very low temperature for a great length of time. This end can be effectually accomplished only by an increased quantity of food. The testimony of Dr. Hayes, the Arctic explorer, is very strong upon this point. He says: "While fresh animal food, and especially fat, is ab-

solutely essential to the inhabitants and travellers in Arctic countries, alcohol is, in almost any shape, not only completely useless but positively injurious. * * * Circumstances may occur under which its administration seems necessary; such, for instance, as great prostration from long-continued exposure and exertion, or from getting wet; but then it should be avoided, if possible, for the succeeding reaction is always to be dreaded; and, if a place of safety is not near at hand, the immediate danger is only temporarily guarded against, and becomes, finally, greatly augmented by reason of decreased vitality. If given at all, it should be in very small quantities frequently repeated, and continued until a place of safety is reached. I have known the most unpleasant consequences to result from the injudicious use of whiskey for the purpose of temporary stimulation, and have also known strong able-bodied men to have become utterly incapable of resisting cold in consequence of the long-continued use of alcoholic drinks."[1]

It is not demonstrated that alcohol increases the capacity to endure severe and protracted bodily exertion. Its influence as a therapeutic agent, in promoting assimilation in certain conditions of defective nutrition, in relieving shock and nervous exhaustion, in sustaining the powers of life in acute diseases characterized by rapid emaciation and abnormally active destructive assimilation, etc., is undoubted; but the consideration of these questions does not belong to physiology.

Distilled Liquors.—The variety of distilled liquors consumed in civilized countries is very great. Brandy, the product of the distillation of wine, is the one most esteemed, and, in therapeutics, generally produces most positively and promptly the beneficial effects of alcohol. As the liquor

[1] HAYES, *Observations upon the Relations existing between Food and the Capabilities of Men to resist Low Temperatures.—American Journal of the Medical Sciences*, July, 1859, p. 117.

most highly prized, it is naturally most subject to adulteration and imitations.

Various other liquors distilled from the fermented products of grains or fruits are in common use. The most important of them are whiskey, which is made from rye, corn, wheat, or oats; gin, made from various grains rectified with turpentine and juniper; rum, made from molasses; and apple or peach-brandy, made from the juices of these fruits. Liquors are also sometimes made from the potato.

As a rule, the distilled liquors contain a little more than fifty per cent., by volume, of alcohol, specific gravity, ·825. Alcohol is undoubtedly more injurious taken in this form than in any other, as its quantity is large, and it is unmixed with the tonic and nutritive principles contained in many wines and malt-liquors. The gravest effects of the abuse of alcoholic beverages, which are, unfortunately, so common in countries where spirit-drinking prevails, are almost unknown where the light wines are the ordinary drink of all classes.

Wines, Malt-Liquors, etc.—The fermented juice of the grape furnishes an almost infinite variety of wines. These are called full-bodied or light, as they contain more or less alcohol. The stronger wines, such as port, madeira, and sherry, contain from fifteen to twenty-five per cent. of alcohol; while the lighter wines, such as claret, sauterne, and hock, contain from ten to fifteen per cent. Every distinct variety of wine contains peculiar flavoring and aromatic principles, either characteristic of the grape or produced in the process of manufacture.

As wine contains a variety of principles, chiefly non-nitrogenized matters, with organic acids and salts, its effects upon the system are somewhat different from those of alcohol or the distilled liquors. The following are the constituents found, in variable proportions, in most wines:[1]

[1] PEREIRA, *A Treatise on Food and Diet*, New York, 1848, p. 202.

Constituents of Wine.

Water,
Alcohol,
Bouquet (volatile oil? an ether?),
Sugar,
Gum,
Extractive matter,
Gluten (except when tannin is present),
Acetic acid,
Bitartrate of potash,
Tartrate of potash and alumina (in German wines),
Sulphate of potash,
Chlorides of potassium and sodium,
Tannin, } (in red wines),
Coloring matter of the husk, }
Carbonic acid (in champagne and other effervescing wines).

As the proportion of alcohol in many wines is quite small, it is only when they are taken in quantity that its disturbing effects upon the system are manifested. Wines supply, on the other hand, many important saline principles, and some have a very decided action as tonics. It must be borne in mind, however, that wines are very often adulterated and imitated. They then contain ordinary spirit, with extraneous coloring and flavoring principles which are often highly injurious.

The sparkling wines are made from the juice of the grape treated in such a way as to increase the production of carbonic acid; a process which generally involves the addition of glucose. The exhilarating properties of the carbonic acid, added to those of the alcohol, render these wines more rapidly stimulating in their effects than other beverages which contain an equal amount of alcohol. Champagne is often the best diffusible stimulant that can be employed, in certain diseases which demand prompt and vigorous support of the vital powers.

In many parts of the United States, the manufacture of wine from native grapes has assumed considerable importance. The Catawba wines, of Ohio, the California, and the North Carolina wines have become quite celebrated. Though these are of rich flavor and possess many good qualities, it will be many years before wine can be produced in this country equal in delicacy to the products of the vineyards of the old world.

Malt-liquors (beer, ale, porter, etc.) are prepared from malted barley, flavored with hops. They contain a very small quantity of alcohol; in the milder beverages of this class, the proportion being from one to four per cent., and in the stronger from six to eight per cent. All varieties contain a certain proportion of carbonic acid, which is particularly abundant when the liquor has been kept in bottles. The principal difference between malt-liquors and other alcoholic beverages is that they contain a large proportion of saccharine and nitrogenized matters. These are in such quantity that malt-liquors possess considerable importance as alimentary articles. In therapeutics, the bitter principle of the hop acting as a tonic, the nutritive action of the solid ingredients, and the stimulant effect of the alcohol, combine to render the malt-liquors very valuable in debilitated conditions of the system, or in the convalescence from exhausting diseases.

The following is the composition of good French beer, like that generally called Strasbourg beer. The heavy English and Scotch ales and porter generally contain a larger proportion of alcohol:

Composition of Beer.[1]

Water	947·00
Alcohol	4·50
Dextrine, glucose, and substances of this class	41·40
Nitrogenized substances	5·26
Mineral salts	1·84
Bitter principle, aromatic essence (quantity not determined).	
	1,000·00

[1] PAYEN, *Précis Théorique et Pratique des Substances Alimentaires*, Paris,

Light and agreeable beverages made from the juice of apples or of pears are in common use. When first made, cider contains the organic acids and salts of the fruit, with a large quantity of sugar. It is then called sweet cider, and contains little or no alcohol. After it has fermented, the sugar in part or entirely disappears, alcohol is formed in considerable quantity (from 5·21 to 9·87 per cent.),[1] and the liquor is then called hard cider. Under proper conditions, acetous fermentation soon converts the liquid into vinegar. During the process of fermentation, carbonic acid is produced in large quantity, and if the liquor be made of good apples and be bottled at the proper time, its flavor is little inferior to that of ordinary champagne. The effects of cider upon the system are substantially those of the light white wines.

Perry, a beverage manufactured to a considerable extent in England from pears, is little used in this country. When new it is sweeter than cider, and possesses the flavor of the pear. By fermentation a liquor is produced, resembling cider in most regards, but containing about fifty per cent. more alcohol.

Coffee.

Coffee is an article consumed daily by many millions of human beings, in all quarters of the globe. In armies it has been found indispensable, enabling men on moderate rations to perform an amount of labor which would otherwise be impossible. After exhausting efforts of any kind there is no article which relieves the overpowering sense of fatigue so completely as coffee. Army-surgeons say that at night, after a severe march, the first desire of the soldier is for coffee, hot or cold, with or without sugar, the only essential being a sufficient quantity of the pure article. This has been the universal experience in the late civil war; the rations of coffee issued by the United States Government be-

1865, p. 462. In copying this table an evident error (957 instead of 947 of water) has been corrected.

[1] DUNGLISON, *Medical Lexicon*, Philadelphia, 1857, p. 984.

ing abundant and pure, though not, of course, of the quality possessing the most delicate flavor. Almost every one can bear testimony from personal experience of the effects of coffee in relieving the sense of fatigue after mental or bodily exertion, and in increasing the capacity for labor, especially mental, by producing wakefulness and clearness of intellect. From these facts the importance of coffee, either as an alimentary article, or as taking the place, to a certain extent, of aliment, is apparent.

Except in persons who, from idiosyncracy, are unpleasantly affected by it, coffee, taken in moderate quantity and at proper times, produces an agreeable sense of tranquillity and comfort, with, however, no disinclination to exertion, either mental or physical. Its immediate influence upon the system, which is undoubtedly stimulant, is peculiar, and is not followed by reaction or unpleasant after-effects. Habitual use makes coffee almost a necessity, even in those who are otherwise well nourished and subject to no extraordinary mental or bodily strain. Taken in excessive quantity, or in those unaccustomed to it, particularly when taken at night, it produces persistent wakefulness. These effects are so well known that it is often taken for the purpose of preventing sleep.

Experimental researches have shown that the use of coffee permits a reduction in the quantity of food, in workingmen especially, much below the standard which would otherwise be necessary to maintain the organism in a proper condition. In the observations of De Gasparin upon the regimen of the Belgian miners, it was found that the addition of a quantity of coffee to the daily ration enabled them to perform their arduous labors on a diet which was even below that found necessary in prisons and elsewhere where this article was not employed.[1] Numerous experiments have shown that coffee

[1] The diet of the miners of Charleroi, where these observations were made, was evidently deficient in nitrogenized matter, the quantity of nitrogen which it represented, aside from the coffee, being but 14·82 grammes (228·7 grains). But on this diet, with the addition of coffee, De Gasparin found that the vital energies

diminishes the absolute quantity of urea discharged by the kidneys.[1] In this respect, as far as has been ascertained, the action of coffee is like that of alcohol, and may reasonably be supposed to retard destructive assimilation; with the important difference that it is followed by no unfavorable after-effects, and can be used in moderation for an indefinite time with advantage.

Dr. Hayes, the Arctic explorer, in comparing the properties of alcohol and tea and coffee in enabling men to resist cold and endure hardships in the Arctic regions, gives the highest praise to the latter articles. In comparing tea and coffee he says that "Dr. Kane's parties, after repeated trial, took most kindly to coffee in the morning and tea in the evening. The coffee seemed to last throughout the day, and the men seemed to grow hungry less rapidly after taking it than after drinking tea, while tea soothed them after a day's hard labor, and the better enabled them to sleep. They both operated upon fatigued and over-taxed men like a charm, and their superiority over alcoholic stimulants was very marked."[2] These facts are highly interesting, for there could be no better opportunity of testing the real value of such

and muscular power were well developed. The following was the ordinary diet, reduced to ounces av. and grains. There was an abundance of good white bread, but the quantity of meat was evidently insufficient:

Coffee	1 oz. 34 grains.
Chiccory	1 oz. 34 "
Milk	a little less than half a pint.
Bread	35 oz. 121 grains.
Butter	2 " 51 "
Green vegetables	26 " 200 "
Meat	2 " 251 "

De Gasparin, *Note sur le Régime des Mineurs Belges.—Comptes Rendus*, Paris, 1850, tome xxx., p. 400.

[1] Hammond, *Urological Contributions.—American Journal of the Medical Sciences*, January, 1855; and Johnston, *Chemistry of Common Life*, New York, 1859, vol. i., p. 168, note.

[2] Hayes, *op. cit.—American Journal of the Medical Sciences*, July, 1859, p. 118.

agents than in men thus subjected to intense cold and extraordinary hardships.

A study of the composition of coffee shows a considerable proportion of what must be considered as alimentary matter. The following is the result of the latest analyses by Payen:

Composition of Coffee.

Cellulose	34·
Water (hygroscopic)	12·
Fatty substances	10 to 13·
Glucose, dextrine, indeterminate vegetable acid	15·500
Legumine, caseine, etc.	10·
Chlorolignate of potash and caffeine	3·5 to 5·
Nitrogenized organism	3·
Free caffeine	0·800
Concrete, insoluble essential oil	0·001
Aromatic essence, of agreeable odor, soluble in water	0·002
Mineral substances: potash, magnesia, lime, phosphoric, silicic, and sulphuric acid and chlorine	6·697
	100·000

The above is the composition of raw coffee, but the berry is never used in that form, being always subjected to torrification before an infusion is made. The roasting should be conducted slowly and gently until the grains assume a chestnut-brown color. During this process the grains are considerably swollen, but they lose from sixteen to seventeen per cent. in weight. A peculiar aromatic principle is also developed. If the torrification be pushed too far, much of the agreeable flavor is lost, and an acrid empyreumatic principle is produced. An infusion of fifteen hundred grains of roasted and ground coffee in about a quart of boiling water, the infusion made by simple percolation, contains about three hundred grains of the soluble principles. According to Payen, this contains about one hundred and forty grains of nitrogenized matters, and one hundred and fifty-three grains of fatty, saccharine, and saline substances. There is every reason to suppose that these principles are assimilated;

[1] *Op. cit.*, p. 414.

and an infusion of coffee, with milk and sugar, presents, therefore, a considerable variety and quantity of alimentary matter. The peculiar stimulant effects of coffee are probably due to the caffeine and volatile oil.

The varieties of coffee in common use are very numerous. The best in the market is the Arabian, or Mocha. The characteristic aroma of coffee is developed by age, which improves to a very great extent some of the inferior varieties. The best Mocha coffee requires, after it is gathered, three or four years to ripen. In this country and in Europe, coffee is prepared for use by simply making an infusion of the roasted and pulverized berry in hot water, either by boiling or by simple percolation. The aromatic and active principles are best extracted by the latter process. They are but slightly soluble in cold water.

An adulteration of coffee, so common as to demand the consideration of the physiologist, consists in the addition of the chiccory-root, cut into small pieces, dried, roasted, and pulverized. This gives a rich brown color to the infusion, and its flavor, not unlike that of coffee itself, is not disagreeable. It has, however, none of the stimulating effects before described; but is used purposely, to a great extent, by many who do not seek for the peculiar stimulant influence of the pure article.

In the countries where coffee is grown, the leaves of the shrub, roasted and made into an infusion, are quite commonly used. Their effects upon the system are similar to those of coffee, and it is said that the natives prefer the leaves to the berry.[1]

Tea.

An infusion of the dried and prepared leaves of the tea-plant is perhaps as common a beverage as coffee, and taking into consideration its immense consumption in China and Japan, is actually used by a greater number of persons. Its

[1] JOHNSTON, *Chemistry of Common Life*, New York, 1859, vol. i., p. 157.

effects upon the system are similar to those of coffee, but are generally not so marked. Ordinary tea, taken in moderate quantity, like coffee, relieves fatigue and increases mental activity, but does not usually induce such persistent wakefulness.

It is unnecessary to describe all the varieties of tea in common use. There are, however, certain varieties, called green teas, which present important differences, as regards composition and physiological effects, from the black teas, which are more commonly used. The following is a comparative analysis of these two varieties by Mulder:[1]

Composition of Tea.

Constituents.	Chinese.		Javanese.	
	Hyson.	Congou.	Hyson.	Congou.
Volatile oil	0·79	0·60	0·98	0·65
Chlorophylle	2·22	1·84	3·24	1·28
Wax	0·28	——	0·32	——
Resin	2·22	3·64	1·64	2·44
Gum	8·56	7·28	12·20	11·08
Tannin	17·80	12·88	17·56	14·80
Theine	0·43	0·46	0·60	0·65
Extractive	22·80	19·88	21·68	18·64
Apotheme[2]	——	1·48	——	1·64
Extract obtained by hydrochloric acid	23·60	19·12	20·36	18·24
Albumen	3·00	2·80	3·64	1·28
Fibrous matter	17·08	28·32	18·20	27·00
	98·78	98·30	100·42	97·70
Salts included in the above	5·56	5·24	4·76	5·36

Both tea and coffee possess peculiar organic principles. The active principle of tea is called *theine*, and the active principle of coffee, *caffeine*. These have been found to be identical in ultimate composition; their formula being $C_8H_5O_2N_2$. As they are supposed to be particularly active in producing

[1] Pereira, *Food and Diet*, New York, 1843, p. 190.

Hyson is a green tea, and Congou is black. With regard to the proportion of theine in teas, there is considerable difference of opinion. Payen (*op. cit.*, p. 427) quotes the analyses of Peligot, which give from 2·34 to 3 parts per 100. He also found from 20 to 30 per cent. of nitrogenized matter.

[2] A peculiar brown deposit which slowly takes place in vegetable extracts (Berzelius).

the peculiar effects upon the nervous system which are characteristic of both tea and coffee, there is good reason to suppose that they are also identical in their physiological effects. Theine (or caffeine) exists in greater proportion in tea than in coffee; but, as a rule, much more soluble matter is employed in the preparation of coffee, which may account for its more marked effects upon the system.

Green tea, especially in those unaccustomed to its use, frequently produces nervous tremor, wakefulness, and disturbed sleep—when sleep can be obtained—palpitations, and other disturbances usually termed nervous. In some persons these unpleasant effects may be overcome by habit; and many constantly use a mixture of equal parts of black and green tea with no unpleasant effects. The peculiar effects of green tea are attributed to the volatile oil, which it contains in great abundance.[1]

Tea is prepared for drinking by rapidly making an infusion of the leaves with hot water. The aroma is nearly destroyed by boiling. The proportion generally used is about three hundred grains of tea to a quart of water. The tea is first covered with boiling water, and allowed to steep, or "draw," for from ten to fifteen minutes, in a warm place; and boiling water is then added in the quantity desired. Green tea, treated in this way, yields about twenty per cent. of soluble matters, and black tea, about twenty-three per cent.[2]

Chocolate.

Chocolate is made from the seeds of the cocoa-tree, roasted, deprived of their husks, and ground with warm rollers into a pasty mass with sugar, flavoring substances being sometimes

[1] It is a question still undecided whether green tea be actually a distinct variety, or whether it differ from black only in the mode of curing. The leaves of green tea are smaller and younger when gathered, and are cured more rapidly than black tea.

[2] PAYEN, *op. cit.*, p. 428.

added. It is then made into cakes, cut into small pieces, or scraped to a powder, and boiled with milk or milk and water, when it forms a thick, gruel-like drink, which is highly nutritive, and has some of the exhilarating properties of coffee and tea. Beside containing a large proportion of nitrogenized matter resembling albumen, the cocoa-seed is particularly rich in fatty matter, and contains a peculiar principle, theobromine, analogous to caffeine and theine, which is supposed to possess similar physiological properties.

The following is a late analysis by Payen[1] of the cocoa-seeds freed from the husks, but not roasted. Torrification has the effect of developing the peculiar aromatic principle, and moderating the bitterness, which is always more or less marked:

Composition of Kernels of Cocoa.

Fatty matter (cocoa-butter)	48 to 50
Albumen, fibrin, and other nitrogenized matter	21 " 20
Theobromine	4 " 2
Starch (with traces of saccharine matter)	11 " 10
Cellulose	3 " 2
Coloring matter, aromatic essence	traces.
Mineral substances	3 to 4
Hygroscopic water	10 to 12
	100 100

It is evident, from the above table, that cocoa with milk and sugar, the ordinary form in which chocolate is taken, must form a very nutritious mixture. Taken with a little bread, it readily relieves hunger, and supplies nearly all the principles absolutely necessary to nutrition. Its influence as a stimulant, supplying the place of matter which is directly assimilated and retarding destructive assimilation, is dependent, if it exists at all, upon the theobromine; but its stimulating properties are slight as compared with coffee and tea.

A drink called cocoa is sometimes made of the seeds roasted entire and mixed with a little starchy matter, but

[1] Ibid., p. 400.

this is not so delicate in flavor as chocolate. A brown mucilaginous infusion is sometimes made of the husks (shells). This has a slight chocolate-flavor, but does not possess the nutrient properties of the kernels.

Quantity and Variety of Food necessary to Nutrition.

The inferior animals, especially those not subjected to the influence of man, regulate by instinct the quantity and kind of food which they consume. The same is true of man during the earliest periods of his existence; but later in life, the diet is variously modified by taste, habit, climate, and what may be termed artificial wants. It is usually a safe rule to follow the appetite with regard to quantity, and the tastes—when they are not manifestly vitiated or morbid—with regard to variety. The cravings of nature indicate when to change the form in which nourishment is taken; and that a sufficient quantity has been taken is manifested by a sense, not exactly of satiety, but of evident satisfaction of the demands of the system. During the first periods of life, the supply must be a little in excess of the actual loss in order to furnish materials for growth. During the latter periods, the quantity of nitrogenized matter assimilated is somewhat less than the loss; but in adult age, the system is maintained at a tolerably definite standard by the assimilation of material about equal in quantity to that which is discharged in the form of excretions.

Although the loss of substance by destructive assimilation creates and regulates the demand for food, it is an important fact, never to be lost sight of, that the supply of food has a very great influence upon the quantity of the excretions. As an illustration of this, we may take the influence of food upon the exhalation of carbonic acid;[1] and this is but an example of what takes place with regard to the other excretions. The quantity of the excretions is even more strikingly modified by exercise, which, within physiological limits, in-

[1] See vol. i., Respiration, p. 435 *et seq.*

creases the vigor of the system, provided the increased quantity of food required be supplied.

While a certain amount of waste of the system is inevitable, it is a conservative provision of nature, that when the supply of new material is diminished life is preserved—not, indeed, in all its vigor—by a corresponding reduction in the quantity of excretions; and, in the same way, the vital forces are retained after complete deprivation of food much longer than if destructive assimilation proceeded always with the same activity.

As regards the quantity of food necessary to maintain the system in proper condition, it is evident that this must be greatly modified by habit, climate, the condition of the muscular system, age, sex, etc., as well as idiosyncrasies.

The daily loss of substance which must be supplied by material introduced from without is very great.[1] A considerable portion of this discharge takes place by the lungs, and the mode of introduction of gaseous principles to supply part of this waste belongs to the subject of respiration. The most abundant discharge which is compensated by absorption from the alimentary canal is that of water, both in a liquid and vaporous condition. The entire quantity of water daily removed from the system has been estimated at about four and a half pounds;[2] and, assuming that there is no evidence of its production in the organism, an equal quantity must necessarily be introduced. The quantity which is introduced in the form of drink varies with the character of the food. When the solid articles contain a large proportion of water, the quantity of drink may be diminished; and it is possible, by taking a large proportion of the watery vegetables, to do without drink altogether.[3]

[1] Prof. Dalton estimates that the daily discharges from the body, including the pulmonary and cutaneous exhalations, amount to a little more than seven pounds avoirdupois. (*Human Physiology*, Philadelphia, 1864, p. 363.)

[2] DALTON, *op. cit.*, p. 70.

[3] Prof. Chas. A. Lee gives a number of examples of persons who were not in the habit of taking water, except that which is contained in the food; but in these

There is no article the consumption of which is so much a matter of habit as water, any excess which may be taken being readily removed by the kidneys, skin, and lungs. Prof. Dalton estimates the daily quantity necessary for a full-grown, healthy male at fifty-two fluid ounces, or 3·38 lbs. avoirdupois.[1]

The quantity of solid food necessary to the proper nourishment of the body is shown by estimating the solid matter in the excretions; and the facts thus ascertained correspond very closely with the quantity of material which the system has been found to actually demand. The estimates of Payen, the quantity of carbon and of nitrogenized matter in a dry state being given, are generally quoted and adopted in works on physiology. According to this observer, the following are the daily losses of the organism:

Carbon (or its equiv.)	Respiration, 3,868·5 grs. / Excretions, 926·04 "	4,794·54 grs. (10·93 oz. av.)
Nitrogenized substances (with 308·68 grs. of Nit.)		2,006·42 grs. (4·58 oz. av.)
		6,800·96 grs. (15·51 oz. av.)

From this he estimates that the normal ration, supposing the food to consist of lean meat and bread, is as follows:[2]

		Nitrogenized Substances.		Carbon.
Bread.....	15,434 grs. (35·27 oz.)	=1,080·38 grs.	and	4,630·2 grs.
Meat......	4,412·12 grs. (10·09 oz.)	= 930·05 grs.	and	485·55 grs.
	19,846·12 grs. (45·36 oz.)	2,010·43 grs.		5,115·75 grs.

This daily ration, which is purely theoretical, is shown by actual observation to be nearly correct. Prof. Dalton says: "From experiments performed while living on an ex-

cases the diet consisted of vegetables of the most succulent kind. He mentions one case in which water was not taken for more than a year—during that time the subject not experiencing the sensation of thirst more than two or three times, and then after copious perspiration from working in hot weather. (PEREIRA, *Treatise on Food and Diet*, edited by CHARLES A. LEE, M. D., New York, 1843, p. 277.)

[1] *Op. cit.*, p. 113.

[2] PAYEN, *Substances Alimentaires*, Paris, 1865, p. 482. The weights have been reduced from grammes to troy grains, and ounces av.

clusive diet of bread, fresh meat, and butter, with coffee and water for drink, we have found that the entire quantity of food required during twenty-four hours by a man in full health and taking free exercise in the open air, is as follows:

Meat	16 ounces,	or 1·00 lb. avoirdupois.
Bread	19 "	" 1·19 " "
Butter or fat	3½ "	" 0·22 " "
Water	52 fluid oz.	" 3·38 " "

That is to say, rather less than two and a half pounds of solid food, and rather over three pints of liquid food."[1]

Bearing in mind the great variations in the nutritive demands of the system in different persons, it may be stated, in general terms, that in an adult male, from ten to twelve ounces of carbon, and from four to five ounces of nitrogenized matter (estimated dry) are discharged from the organism, and must be replaced by the ingesta; and this demands a daily consumption of from two to three pounds of solid food; the quantity of food depending, of course, greatly on its proportion of solid, nutritive principles.[2]

It is undoubtedly true that the daily ration has frequently been diminished considerably below the physiological standard in charitable institutions, prisons, etc.; but when there is complete inactivity of body and mind, this produces no other effect than that of slightly diminishing the weight and strength. The system then becomes reduced without any actual disease, and there is simply a diminished capacity for labor. But in the alimentation of large bodies

[1] *Loc. cit.*

[2] The correspondence between the absolute quantities of nitrogen and carbon contained in the excretions, and their proportions in the food necessary to sustain the system, is truly remarkable. In elaborating this idea Payen (*op. cit.*, p. 488) has prepared a table giving the proportions of nitrogen, carbon, fatty matter, and water in a hundred different articles, comprising nearly all the important varieties of food. This table is of great value as showing the nutritive power of different articles entering into the dietaries of armies, charitable institutions, etc., when the quantity of food for a large number of persons must be regulated by some fixed standard.

of men, subjected to exposure, and frequently called upon to perform great labor, the question of food is of vital importance, and the men collectively are like a powerful machine in which a certain quantity of material must be furnished in order to produce the required amount of force. This important physiological fact is most strikingly exemplified in armies; and the history of the world presents few examples of warlike operations in which the efficiency of the men has not been impaired by insufficient food. In the Crimea, this was often the case with both the English and French troops. The ration of the British soldier, at home stations, is sixteen ounces of bread, or twelve ounces of biscuit, and sixteen ounces of meat. This gives 6·48 ounces of carbon, and 3·62 ounces of nitrogenized matter;[1] a quantity which is acknowledged to be insufficient; but the soldier is expected to purchase certain articles for himself, such as coffee, sugar, fresh vegetables, etc. In the Crimea it was found necessary to deviate from the regular ration, and allow to each soldier twenty-four ounces of bread and sixteen ounces of meat, with rice, sugar, coffee, and a little spirit.[2]

The United States army-ration is the most generous in the world; and the result has been that, in the recent civil war, scurvy and other diseases which are usually so rife in armies subject to the exposure and fatigue incident to grand military operations have been comparatively rare. In some of the long and arduous campaigns of the war, the marches made by large bodies of troops and the labor performed showed an amount of endurance heretofore unknown in military history. The excellent physical condition of the men was further evidenced by the remarkable percentage of recoveries after serious wounds and surgical operations, and

[1] Calculated from Payen's table (*loc. cit.*). The bread is assumed to contain the same principles as the white, French bread, and the meat to contain bone equal to one-fifth of its weight.

[2] HAMMOND, *A Treatise on Hygiene, with special reference to the Military Service*, Philadelphia, 1863, p. 561.

the slight prevalence of the ordinary diseases, except those of malarial origin.

The following is the army ration of the United States:[1]

Daily Ration of the United States Soldier.

Bread or flour	22	ounces.
Fresh or salt beef (or pork or bacon, 12 oz.)	20	"
Potatoes (three times per week)	16	"
Rice	1·6	"
Coffee (or tea 0·24 oz.)	1·6	"
Sugar	2·4	"
Beans	0·64	gill.
Vinegar	0·32	"
Salt	0·16	"

The bread, meat, and potatoes in the above ration contain 9·28 of carbon and 4·68 of nitrogenized matter; in addition to which are the alimentary principles contained in the rice, beans, sugar, and coffee, with the peculiar stimulant effect of the coffee. The United States soldier does not receive alcohol unless exposed to extraordinary privations or fatigue.

The influence of diet upon the capacity for labor was well illustrated by a comparison of the amount of work accomplished by English and French laborers in 1841, on a railroad from Paris to Rouen. The French laborers engaged on this work were able at first to perform only about two-thirds of the labor accomplished by the English. It was suspected that this was due to the more substantial diet of the English, which proved to be the fact; for when the French laborers were subjected to a similar regimen, they were able to accomplish an equal amount of work.[2]

In all observations of this kind, and they are very numerous, it has been shown that an animal diet is much more favorable to the development of the physical forces than one consisting mainly of vegetables.

[1] HAMMOND, *op. cit.*, p. 564.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 89.

Climate has an important influence on the quantity of food demanded by the system. It is generally acknowledged that the consumption of all kinds of food is greater in cold than in warm climates, and almost every one has experienced in his own person a considerable difference in the appetite at different seasons of the year. Travellers' accounts of the quantity of food taken by the natives of the frigid zone are almost incredible. They speak of men consuming over a hundred pounds of meat in a day; and a Russian admiral, Saritcheff, mentions an instance of a man who, in his presence, ate at a single meal a mess of boiled rice and butter weighing twenty-eight pounds.[1] Though it is difficult to regard these statements with entire confidence, the general opinion that the appetite is greater in cold than in warm climates is undoubtedly well founded. Dr. Hayes, the Arctic explorer, states, from his personal observation, that the daily ration of the Esquimaux is from twelve to fifteen pounds of meat, about one-third of which is fat. On one occasion he saw an Esquimau consume ten pounds of walrus-flesh and blubber at a single meal, which lasted, however, several hours. The continued low temperature he found had a remarkable effect on the tastes of his own party. With the thermometer ranging from $-60°$ to $-70°$ Fahr. there was a continual craving for a strong animal diet, particularly fatty substances. Some members of the party were in the habit of drinking the contents of the oil-kettle with evident relish.[2]

Necessity of a Varied Diet.

In considering the nutritive value of the various alimentary principles, the fact that no single one of them is capable of supplying all the material for the regeneration of the organism has frequently been mentioned. The normal appetite,

[1] COCHRANE, *A Pedestrian Journey through Russia, etc.*—CONSTABLE'S *Miscellany*, Edinburgh, 1829, vol. i., p. 194.

[2] HAYES, *An Arctic Boat-Journey*, Boston, 1860, pp. 257–259, and *American Journal of the Medical Sciences*, July, 1859, p. 114 *et seq.*

which is our best guide as regards the quantity and the selection of food, indicates that a varied diet is necessary to proper nutrition. This fact is also exemplified in a marked degree in long voyages and in the alimentation of armies, when, from necessity or otherwise, the necessary variety of aliment is not presented. Analytical chemistry fails to show why this change in alimentary principles is necessary, or in what the deficiency in a single kind of diet consists; but it is nevertheless true that after the organic constituents of the organism have appropriated the nutritious elements of particular kinds of food for a certain time, they lose the power of inducing the catalytic changes necessary to proper nutrition, and a supply of other material is imperatively demanded. This fact is particularly well marked when the diet consists in great part of salted meats, though it is also the case when any single variety of fresh meat is constantly used. After long confinement to a diet restricted as regards variety, a supply of other material, such as fresh vegetables, the organic acids, and articles which are called generally anti-scorbutics, becomes indispensable; otherwise the modifications in nutrition and in the constitution of the blood incident to the scorbutic condition are sure to be developed.

It is thus apparent that an adequate quantity and proper quality of food is not all that is demanded in alimentation; and those who have the responsibility of regulating the diet of a large number of persons must bear in mind the fact that the organism demands considerable variety. Fresh vegetables, fruits, etc., should be taken at the proper seasons. It is almost always found, when there is of necessity some sameness of diet, that there is a general craving for particular articles, and these, if possible, should be supplied. This was frequently exemplified in the late war. At times when the diet was necessarily somewhat monotonous, there was an almost universal craving for onions and raw potatoes, which were found by the surgeons to be excellent anti-scorbutics.

In those who supply their own food the question of vari-

ety of diet generally regulates itself; and in institutions, it is a good rule to follow as far as possible the reasonable tastes of the inmates. In individuals, particularly females, it is not uncommon to observe marked disorders in nutrition attributable to want of variety in the diet as well as an insufficient quantity of food, as a matter of education or habit.

The physiological effects of a diet restricted to a single alimentary principle, or a few articles, have been pretty closely studied both in the human subject and in the inferior animals. Magendie long since demonstrated that animals subjected to a diet composed exclusively of non-nitrogenized articles died in a short time with all the symptoms of inanition. The same result followed in dogs confined to white bread and water; but these animals lived very well on the brown military bread, as this contains a greater variety of alimentary principles.[1] Facts of this nature were multiplied by the "Gelatine commission," and the experiments were extended to nitrogenized substances, and articles containing a considerable variety of alimentary principles.[2] In these experiments it was shown that dogs could not live on a diet of pure musculine; the appetite failing entirely, from the forty-third to the fifty-fifth day.[3] They were nourished perfectly well by gluten, which, as we have seen, is composed of a number of different alimentary principles.

Among the conclusions arrived at by this commission

[1] MAGENDIE, *Précis Elémentaire de Physiologie*, Paris, 1817, tome ii., p. 390 *et seq.* The fourth edition of this work (Paris, 1836, p. 504) contains the experiments of Magendie upon the comparative nutritive power of white and of brown bread. In 1827, Tiedemann and Gmelin published an account of experiments on geese which were confined to an exclusive diet respectively of gum, sugar, starch, and coagulated white of egg. All of them died: the one fed with gum, on the sixteenth day; the one fed with sugar, on the twenty-first day; the two fed with starch, on the twenty-fourth and twenty-seventh days, respectively; and the one fed with white of egg, on the twenty-sixth day.—(*Recherches Expérimentales, Physiologiques et Chimiques, sur la Digestion*, Paris, 1827, Second Partie, p. 266.)

[2] The results of the inquiry into the nutritive value of gelatine have already been considered. See page 49.

[3] *Comptes Rendus*, Paris, 1841, p. 275.

which bear particularly on the questions under consideration, were the following:

"Gelatine, albumen, fibrin, taken separately, do not nourish animals except for a very limited period and in a very incomplete manner. In general, these substances soon excite an insurmountable disgust, to the point that animals prefer to die of hunger rather than touch them.

"The same principles artificially combined and rendered agreeably sapid by seasoning are accepted more readily and longer than if they were isolated, but ultimately they have no better influence on nutrition, for animals that take them, even in considerable quantity, finally die with all the signs of complete inanition.

"Muscular flesh, in which gelatine, albumen, and fibrin are united according to the laws of organic nature, and when they are associated with other matters, such as fat, salts, etc., suffices, even in very small quantity, for complete and prolonged nutrition."[1]

In Burdach's treatise on physiology, is an account of some interesting experiments by Ernest Burdach on rabbits, showing the influence of a restricted diet upon nutrition. Three young rabbits from the same litter were experimented upon. One was fed with potato alone, and died on the thirteenth day with all the appearances of inanition. Another fed on barley alone died in the same way during the fourth week. The third was fed alternately day by day with potato and barley, for three weeks, and afterward with potato and barley given together. This one increased in size and was perfectly well nourished.[2]

In 1769, long before any of the above-mentioned experiments were performed, Dr. Stark, a young English physiologist, fell a victim at an early age to ill-judged experiments on his own person on the physiological effects of different

[1] *Op. cit.*, p. 282.

[2] C. F. Burdach, *Traité de Physiologie, traduit par* Jourdan, Paris, 1841, tome ix., p. 249.

kinds of food. He lived for forty-four days on bread and water, for twenty-nine days on bread, sugar, and water, and for twenty-four days on bread, water, and olive-oil; until finally his constitution became broken, and he died from the effects of his experiments.[1]

The late experiments of Dr. Hammond on his own person on the nutritive value of albumen, starch, and gum show the impossibility of sustaining life, even with a substance so nutritious, when combined with other principles, as albumen; and thus confirm, in the human subject, the observations of Magendie and others on the inferior animals.[2]

[1] These remarkable observations were collected and published after the death of Dr. Stark, by Dr. James Carmichael Smyth. (*The Works of the late* WILLIAM STARK, M. D., London, 1798.) In commencing his observations on diet, Dr. Stark says that " Dr. B. Franklin, of Philadelphia, informed me that he himself, when a journeyman printer, lived a fortnight on bread and water, at the rate of 10 lbs. of bread per week, and that he found himself stout and hearty with this diet," (p. 92.)

[2] HAMMOND, *Experimental Researches relative to the nutritive value and physiological effects of Albumen, Starch, and Gum, when singly and exclusively used as Food.—Transactions of the American Medical Association*, 1857.

CHAPTER V.

DIGESTION—PREHENSION AND MASTICATION.

General arrangement of the digestive apparatus—Prehension of solids and liquids—Mastication—Physiological anatomy of the organs of mastication—Enamel of the teeth—Dentine—Cement—Pulp-cavity—Arrangement of the teeth—Anatomy of the maxillary bones—Temporo-maxillary articulation—Muscles of mastication—Muscles which depress the lower jaw—Action of the muscles which elevate the lower jaw and move it laterally and antero-posteriorly—Action of the tongue, lips, and cheeks in mastication—Summary of the process of mastication.

General Arrangement of the Digestive Apparatus.

THE inorganic alimentary principles are, with few exceptions, introduced in the form in which they exist in the blood, and require no preparation or change before they are absorbed; but the organic nitrogenized principles are always united with more or less matter possessing no nutritive properties, from which they must be separated; and even when pure they always undergo certain changes before they become part of the great nutritive fluid. The non-nitrogenized principles also undergo changes in constitution or in form preparatory to absorption. With the varied forms in which food is presented to different animals, we find great differences in the arrangements of the digestive apparatus; from the simple pouch with a single orifice, which constitutes the entire digestive system of many of the infusorial animalcules, to the immense length of intestine, with its numerous glandular appendages, found in the mammalia. In the higher classes of animals, great differences exist in the

anatomy of the digestive organs, particularly as regards the length and capacity of the alimentary canal. In the carnivora, in which the food contains comparatively little indigestible residue, the intestine is but three or four times the length of the body (*i. e.* from the mouth to the anus), and the colon, which receives the residue of digestion, is of small capacity; while in the herbivora, in which the bulk of food, compared with its nutritious principles, is enormous, there are frequently four distinct cavities to the stomach, and the intestine is ten, twelve, and in some (the sheep) twenty-eight times the length of the body, with a colon of very large size. The food of man is derived from both the animal and vegetable kingdom, and in length and capacity, the alimentary canal is between that of the carnivora and the herbivora, being from six to seven times the length of the body.[1]

A full meal probably occupies from two to four hours in its digestion, this depending, of course, on the kind of food, the fineness of its comminution by mastication, etc.[2] The

[1] CUVIER, *Leçons d'Anatomie Comparée*, Paris, 1835, tome iv., Deuxième Partie, p. 173. In this work is given a long and elaborate table of measurements of the intestines as compared with the length of the trunk; the measurements of the intestines, including all between the pylorus and the anus, and the measurement of the trunk, in the mammalia, extending from the mouth to the anus. Taking the latter measurement in the human subject as from two and a quarter to two and a half feet, the length of the intestinal canal would be, in general terms, from fifteen to eighteen feet. This is much less than the estimate generally given in works on anatomy, in which the measurements given vary between twenty and thirty feet. In the natural condition of the parts, the estimate of Cuvier is perhaps pretty near the truth, for the intestines are very extensible, and are much longer when detached from the mesentery and stretched out, than they are *in situ;* but the standard of measurement, *i. e.*, the length of the body, is very indefinite.

[2] This estimate is roughly made from the celebrated experiments of Dr. Beaumont in the case of Alexis St. Martin (*Experiments and Observations on the Gastric Juice and the Physiology of Digestion*, Plattsburg, 1833). In one of these observations, after a meal of roast-turkey, potatoes, and bread, the stomach was found empty in two and a half hours (p. 171). The stomach was found empty one hour and thirty-five minutes after a breakfast of venison-steak, cranberry-jelly, and bread (p. 147). From a large number of observations, Dr. Beaumont concludes "that the time required for the disposal of a moderate meal of the fibrous parts of meat, with bread, etc., is from three to three and a half hours.'

matters taken into the stomach consist generally of all varieties of alimentary principles, and they are exposed to certain mechanical processes in the mouth and alimentary canal, and to the action of various secreted fluids.

In the mouth, the food is divided, as the occasion demands, by the incisor teeth, and is then passed, by the action of the cheeks and tongue, between the molars, where it is subjected to mastication. During this process it is mixed with the various fluids which compose the saliva, and becomes more or less coated with the tenacious secretions of the mucous follicles of the buccal cavity. It is, or should be, reduced in the mouth to a pultaceous mass, with which the saliva, particularly that from the parotid gland, is thoroughly incorporated; while the secretion of the submaxillary and the sublingual gland, being more viscid, has a greater tendency to coat the exterior.

By the action of the tongue, the alimentary bolus, after mastication, is passed back to the pharynx, where, by the successive action of the constrictor muscles, it is forced into the œsophagus. This tube leads from the pharynx to the stomach, and is provided with thick muscular walls, by the contraction of which the food is passed into this cavity, which serves at once as a receptacle for the food, and an important active organ in digestion.

The stomach is covered externally by the general peritoneal covering of the abdominal organs. It is provided with a mucous membrane, which secretes the gastric juice and absorbs the water with inorganic and other principles in solution. The stomach also has muscular walls, composed of un-

In this he only has reference to the action of the stomach; but the food passes gradually from this organ into the intestinal canal, and the digestion is then completed very rapidly. In many instances, after a good breakfast, Dr. Beaumont found the stomach empty in less than two hours; but it sometimes required more than four hours to dispose of the food taken at dinner. In later observations on St. Martin, in 1856, by Prof. F. G. Smith, of Philadelphia, it is stated that food was never found in the stomach for more than two hours.—(*Expériences sur la Digestion.*—*Journal de la Physiologie*, Paris, 1858, tome i., p. 146.)

striped muscular fibres arranged in two principal layers. Nearly all the principles contained in food are modified by the gastric juice, and some are completely liquefied and absorbed in the stomach. By the action of the gastric juice, the food, comminuted and incorporated with the fluids of the mouth, is further reduced to a pultaceous mass, which was formerly called the chyme; the muscular movements of the stomach turning it over and over, so that it may become thoroughly incorporated with the fluids. These movements have a tendency to force the food, as it becomes sufficiently liquefied, into the small intestine; and a large collection of circular muscular fibres, called sometimes the pyloric muscle, stands at the pylorus as a guard, allowing the liquid portions to pass gradually through, but sending back the larger masses to be further acted upon in the stomach.

By these movements, a great portion of the food, prepared by the action of the stomach, is slowly forced into the small intestine. This tube, from fifteen to twenty feet in length, is covered with peritoneum and loosely bound to the spinal column by the mesentery, which is formed of the two folds of the peritoneum, and is sufficiently long to allow of free movements of the intestines over each other and in the abdominal cavity, except the first few inches, where it is pretty firmly attached to the posterior abdominal wall. The small intestine commences by a dilated portion eight or ten inches in length, called the duodenum. The remainder is divided into the jejunum and the ileum. The former embraces the upper two-fifths of the intestine, but there is no distinct line of separation between it and the ileum. The mucous membrane lining the small intestine is thick, provided with an immense number of villi, and, particularly in the upper portion, is thrown into transverse folds which are called the valvulæ conniventes. These disappear in the lower part of the ileum. They are peculiar to the human subject. Thickly set in the upper part of the duodenum, and scattered through its lower portion and the upper part of the jejunum,

are small compound follicles called the glands of Brunn; and throughout the whole of the intestine are simple, blind follicles, called the follicles of Lieberkühn. These glandular organs secrete the intestinal juice. As the food passes from the stomach into the intestine, it imbibes the bile and pancreatic juice, which are poured into the duodenum, as well as the intestinal juice.

Between the mucous membrane of the small intestine and the peritoneum are two layers of unstriped muscular fibres; by the progressive peristaltic action of which, the food is passed slowly on toward the large intestine. The alimentary principles, liquefied and prepared by digestion, are gradually absorbed by the blood-vessels of the intestinal mucous membrane, and by the lacteals.

The indigestible residue of the food is passed by peristaltic action into the large intestine. This portion of the alimentary canal is from four to six feet in length; and, like the small intestine, has a peritoneal, mucous, and muscular coat. Under ordinary conditions the large intestine is not concerned in digestion. It simply retains the residue of food, with certain excrementitious substances, until its contents are expelled by the act of defecation.

Prehension of Solids and Liquids.

The different modes of prehension form a very interesting part of the physiology of digestion in the inferior animals; but in the human subject, the process is so simple and well known that it demands nothing more than a passing mention. The mechanism of sucking in the infant and of drinking is a little more complicated. In sucking, the lips are closed around the nipple, the velum pendulum palati is applied to the back of the tongue so as to close the buccal cavity posteriorly, and the tongue, acting as a piston, produces a tendency to a vacuum in the mouth, by which the liquids are drawn in with considerable force. This may be done independently of the act of respiration, which is neces-

sarily arrested only during deglutition; for the mere act of suction has never any thing to do with the condition of the thoracic walls. The mechanism of drinking from a vessel is essentially the same. The vessel is inclined so that the lips are kept covered with the liquid, and are closed around the edge. By a gentle sucking action the liquid is then introduced. This is the ordinary mechanism of drinking; but sometimes the head is thrown back and the liquid is poured into the mouth, as in "tossing off" the contents of a small vessel, as a wine-glass.[1]

In drinking from a spoon, or in taking hot liquids, or when it is desired to introduce but a small quantity at a time, the liquid is drawn into the mouth with an act of inspiration. In this process the lips are not covered by the liquid, as in ordinary drinking, and it enters the mouth with a more or less audible sound.

Mastication.

In the human subject, mechanical division of food in the mouth is neither so completely and laboriously effected as in the herbivora, particularly the ruminants, nor is the process so rapid and imperfect as in the carnivora. In order that digestion may take place in a perfectly natural manner, it is necessary that the food, as it is received into the stomach, should be so far comminuted and incorporated with the fluids of the mouth as to be readily acted upon by the gastric juice; otherwise stomach-digestion is prolonged and difficult. Non-observance of this physiological law is a frequent cause of what is generally called dyspepsia. In animals that do not masticate, as some which live exclusively on flesh, the process of stomach-digestion is much more prolonged than

[1] Any one can easily convince himself that the ordinary mechanism of drinking is by suction, by simply analyzing his own movements during this act. The vessel is inclined so as simply to cover the lips, and not sufficiently to pour the liquid into the mouth; and the fact that a suction force is exerted by the mouth becomes very evident when the attention is directed to it.

in the human subject, even when the diet is the same; and it is found that while man must, as a rule, take food two or three times in the day, the carnivorous animals are generally best nourished when food, in proper quantity, is taken but once in the twenty-four hours. In the carnivora, the proportionate quantity of food is greater than in man, and digestion is much more prolonged.

The comparative anatomy of the organs of mastication makes it evident that the human race is designed to live on a mixed diet; but experience has shown that man can be nourished for an indefinite period on a diet composed exclusively of either animal or vegetable principles.

Physiological Anatomy of the Organs of Mastication.

In the adult, each jaw is provided with sixteen teeth, all of which are about equally well developed. The canines, so largely developed in the carnivora, but which are rudimentary in the herbivora, and the incisors and molars, so perfectly developed in the herbivora, are, in man, of nearly the same length. Each tooth presents, for anatomical description, a crown, a neck, and a root or fang. The crown is that portion which is entirely uncovered by the gums; the root is that portion embedded in the alveolar cavities of the maxillary bones; and the neck is the portion, sometimes slightly constricted, situated between the crown and the root, covered by the edge of the gum. Thin sections of the teeth show that they are composed of several distinct structures.

Enamel of the Teeth.—The crown is covered by the enamel, which is by far the hardest structure in the economy. This is white and glistening, and is thickest on the lower portion of the tooth, especially over the surfaces which, from being opposed to each other on either jaw, are most exposed to wear. It here exists in several concentric layers. The incrustation of enamel becomes gradually thinner toward the neck, where it ceases. Microscopical examination

shows that the enamel is made up of pentagonal or hexagonal rods, one end resting upon the subjacent structure, and the other, when there exists but a single layer of enamel, terminating just beneath the cuticle of the teeth. The hardness of the enamel varies in different persons. In some it is so soft that in middle life it becomes worn away from the opposing surfaces, and occasionally the teeth are worn down almost to the gums; while in others the enamel remains over the crown of the tooth even in old age.

The exposed surfaces of the teeth are still further protected by a membrane, from $\frac{1}{30000}$ to $\frac{1}{15000}$ of an inch in thickness, closely adherent to the enamel, called the cuticle of the enamel. This delicate membrane may be demonstrated in thin sections of young teeth by the addition, under the microscope, of weak hydrochloric acid. The acid attacks the enamel, producing little bubbles of gas which press out the membrane from the edge of the preparation, and thus render it apparent. The cuticle presents a strong resistance to reagents, and undoubtedly is very useful in protecting the teeth from the action of acids which may find their way into the mouth.

Dentine.—The largest portion of the teeth is composed of a peculiar structure called dentine, or ivory. In many respects, particularly in its composition, this resembles bone; but it is much harder, and does not possess the lacunæ and canaliculi which are characteristic of the true osseous structure. The dentine bounds and encloses the central cavity of the tooth, extending in the crown to the enamel, and in the root to the cement. It is formed of a homogeneous fundamental substance, which is penetrated by an immense number of canals radiating from the pulp-cavity toward the exterior. These are called the dentinal tubules or canals. They are from $\frac{1}{25000}$ to $\frac{1}{12000}$ of an inch in diameter, with walls of a thickness a little less than their calibre. Their course is slightly wavy or spiral. Commencing at the pulp

cavity, into which these canals open by innumerable little orifices, they are found to branch and occasionally anastomose, their communications and branches becoming more numerous as they approach the external surface of the tooth. The canals of largest diameter are found next the pulp-cavity, and they become smaller as they branch. The structure which forms the walls of these tubules is somewhat denser than the intermediate portion, which is sometimes called the inter-tubular substance of the dentine; but in some portions of the tooth, the tubules are so numerous that their walls touch each other, and there is, therefore, no inter-tubular substance. Near their origin and near the peripheral terminations of the dentinal tubules, are sometimes found solid globular masses of dentine, called dentine-globules, which irregularly bound triangular or stellate cavities of very variable size. These cavities have been considered as lacunæ, like the lacunæ of true bone; but this view is not held by the best and most recent observers. Sometimes these cavities are very numerous, and form regular zones near the peripheral termination of the tubules. The dentine is sometimes marked by concentric lines, indicating a lamellated arrangement. In the natural condition, the dentinal tubules are filled with a clear fluid, which penetrates from the vascular structures in the pulp-cavity.

Cement.—Covering the dentine of the root, is a thin layer of true bony structure, called the cement, or crusta petrosa. This is thickest at the summit and the deeper portions of the root, where it is sometimes lamellated, and becomes thinner near the neck. It finally becomes continuous with the enamel of the crown, so that the dentine is everywhere completely covered. The cement contains true bone-lacunæ and canaliculi, and in very old teeth, a few Haversian canals, except near the neck, where the layer is very thin. It is closely adherent to the dentine and the periosteum lining the alveolar cavities.

Pulp-Cavity.—In the interior of each tooth, extending from the apex of the root or roots into the crown, is the pulp-cavity, which contains a collection of minute blood-vessels and nervous filaments, held together by longitudinal fibres of the white fibrous tissue. This is the only portion of the tooth endowed with sensibility. Its blood-vessels and nerves penetrate by a little orifice at the extremity of the root.

The dentine and enamel of the teeth must be regarded as perfected structures; for when the second or permanent teeth are lost, they are never reproduced, and when these parts are invaded by wear or by decay, they are incapable of regeneration. The integrity of the pulp, even, is not necessary to the stability of the teeth; for examples are numerous in which the pulp loses its vitality from various causes, and yet the tooth remains, is as serviceable as ever, being only discolored by the decomposition of the structures in the pulp-cavity, which can neither escape nor become absorbed.

The descriptive anatomy of the teeth in the human subject shows how well calculated they are to perform their varied functions, and how admirably they are adapted to a diet composed of articles derived from both the animal and vegetable kingdom. The thirty-two permanent teeth are divided as follows:

1. Eight incisors, four in each jaw, called the central and lateral incisors.

2. Four canines, or cuspidati, two in each jaw, just back of the incisors. The upper canines are sometimes called the eye-teeth, and the lower canines, the stomach-teeth.

3. Eight bicuspid—the small, or false molars—just back of the canines; four in each jaw.

4. Twelve molars, or multicuspid, situated just back of the biscuspid; six in each jaw.

The incisors are wedge-shaped, flattened antero-posteriorly, and bevelled at the expense of the posterior face, giving them a sharp cutting edge, which is sometimes perfectly straight, but is generally more or less rounded. The upper

incisors are generally larger and stronger than the lower. In the upper jaw the central incisors are larger than the lateral; while in the lower jaw the lateral incisors are larger than the central. Each of the incisors has but a single root. The special function of the incisor teeth is to divide the food as it is taken into the mouth. The permanent incisors make their appearance from the seventh to the eighth year.

The canines are more conical and pointed than the incisors, and have longer and larger roots, especially those in the upper jaw. Their roots are single. They are used to some extent, in connection with the incisors, in dividing the food; but have no prominent function in tearing the food, as in the carnivora, in which they are extraordinarily developed. The permanent canines make their appearance from the eleventh to the twelfth year.

The bicuspid teeth are shorter and thicker than the canines. Their opposed surfaces are rather broad and are marked by two eminences. The upper bicuspids are somewhat larger than the lower. The roots are single, but in the upper jaw are slightly bifurcated at their extremities. They are used, with the true molars, in triturating the food. The permanent bicuspids make their appearance from the ninth to the tenth year.

The molar teeth, called respectively—counting from before backward—the first, second, and third molars, are the largest of all, and are, *par excellence*, the teeth used in mastication. Their form is that of a cube, rounded laterally, and provided with four or five eminences on their opposed surfaces. The first molars are the largest. They have generally three roots in the upper jaw, and two in the lower; although they sometimes have four and even five roots. The second molars are but little smaller than the first, and resemble them in nearly every particular. The third molars, called frequently the wisdom-teeth, are much smaller than the others, and are by no means so useful in mastication. In the upper jaw the root is grooved or imperfectly divided into three branches;

but in the lower jaw it generally has two distinct branches. The first molars are the first of the permanent teeth; making their appearance between the sixth and the seventh year. The second molars appear from the twelfth to the thirteenth year; and the third molars from the seventeenth to the twenty-first year, and sometimes even much later. In some instances the third molars are never developed.

The upper jaw has ordinarily a somewhat longer and broader arch than the lower; so that when the mouth is closed the teeth are not brought into exact apposition, but the upper teeth overlap the lower teeth both in front and laterally. The lower teeth are all somewhat smaller than the corresponding teeth in the upper jaw, and generally make their appearance a little earlier.

The physiological anatomy of the maxillary bones and of the temporo-maxillary articulation necessarily precedes the study of the muscles of mastication and the mechanism of their action.[1]

The superior maxillary bones are immovably articulated with the other bones of the head, and do not usually take any active part in mastication; but their inferior borders, with the upper teeth embedded in the alveolar cavities, present fixed surfaces against which the food is pressed by the action of the muscles which move the lower jaw.

The inferior maxilla is a single bone. Its body is horizontal, of a horse-shoe shape, and in the alveolar cavities in its superior border are embedded the lower teeth. Below the teeth, both externally and internally, are surfaces for the attachments of the muscles concerned in the various movements of the jaw, and one of the muscles of the tongue.

Behind this horizontal body, on either side, is a vertical

[1] The mechanism of mastication in the human subject is more complex than in any of the inferior animals; and it is absolutely necessary to enter into tolerably minute details of the anatomy of the parts concerned in this function, in order to comprehend their physiology.

portion called the ramus. In the adult, this forms nearly a right angle with the body, making what is called the angle of the jaw. Superiorly, the ramus terminates in two processes, separated by a deep groove called the sigmoid notch. The posterior process is the condyle, or condyloid process; the anatomy of which will be considered further on in treating of the temporo-maxillary articulation. The anterior process, called the coronoid process, is for the attachment of the temporal muscle, one of the most powerful of the muscles of mastication. The greater portion of the external surface of the ramus, extending down to the angle, is for the attachment of the masseter muscle. The internal surface of the ramus gives attachment to several muscles, viz.: the external pterygoid, attached to the neck just below the condyle; the temporal, the attachment to the coronoid process being much more extensive on the internal than on the external surface; and the internal pterygoid, which has its attachment at the angle.

Temporo-Maxillary Articulation.—The various classes of mammalia present great differences in the temporo-maxillary articulation—differences which indicate, to a great extent, their natural diet. In the carnivora, the long diameter of the condyle is transverse, and it is so firmly embedded in the deep glenoid cavity of the temporal bone, as to admit of extended movements in but one direction. In these animals, lateral and antero-posterior sliding movements of the jaw are impossible, and there is very little mastication of the food. In the rodentia, the long diameter of the condyle is antero-posterior, the peculiar gnawing movements in these animals requiring a considerable sliding movement of the lower jaw in this direction. In the herbivora, particularly the ruminants, the condyle is small and slightly concave instead of convex, as in most other animals. It moves on a large projecting surface on the temporal bone, and the entire jaw is capable of remarkably extensive lateral movements.

In man, the articulation of the lower jaw with the temporal bone is such as to allow, to a considerable extent, of an antero-posterior sliding movement and a lateral movement, in addition to the ordinary movements of elevation and depression. The condyloid process is convex, with an ovoid surface, the general direction of its long diameter being transverse and slightly oblique from without inward and from before backward. This process is received into a cavity of corresponding shape in the temporal bone, called the glenoid fossa, which is bounded, anteriorily, by a rounded eminence (eminentia articularis), the uses of which will be more fully described in connection with the movements of the jaw.

Between the condyle of the lower jaw and the glenoid fossa, is an oblong, inter-articular disk of fibro-cartilage. This disk is thicker at the edges than in the centre. It is pliable, and so situated that when the lower jaw is projected forward, making the lower teeth project beyond the upper, it is applied to the convex surface of the eminentia articularis and presents a concave surface for articulation with the condyle. One of the uses of this cartilage is to constantly present a proper articulating surface upon the articular eminence, and thus admit of the antero-posterior sliding movement of the lower jaw. It is also important in the lateral movements of the jaw, in which one of the condyles remains in the glenoid cavity, and the other is projected, so that the bone undergoes a slight rotation.

Muscles of Mastication.—To the lower jaw are attached certain muscles by which it is depressed, and others by which it is elevated, projected forward and drawn backward, and moved from side to side. The following are the principal muscles concerned in the production of these varied movements:

Muscles of Mastication.

Muscles which depress the lower jaw.

Muscle.	*Attachments.*
Digastric	Mastoid process of the temporal bone—Lower border of the inferior maxilla near the symphysis; with its central tendon held to the side of the body of the hyoid bone.
Mylo-hyoid	Body of the hyoid bone—Mylo-hyoid ridge on the internal surface of the inferior maxilla.
Genio-hyoid	Body of the hyoid bone—Inferior genial tubercle on the inner surface of the inferior maxilla near the symphysis.
Platysma myoides	Clavicle, acromion, and fascia—Anterior half of the body of the inferior maxilla near the inferior border.

Muscles which elevate the lower jaw, and move it laterally and antero-posteriorly.

Temporal	Temporal fossa—Coronoid process of the inferior maxilla.
Masseter	Malar process of the superior maxilla, lower border and internal surface of the zygomatic arch—Surface of the ramus of the inferior maxilla.
Internal Pterygoid	Pterygoid fossa—Inner side of the ramus and angle of the inferior maxilla.
External Pterygoid	Pterygoid ridge of the sphenoid, the surface between it and the pterygoid process, external pterygoid plate, and the tuberosity of the palate and the superior maxillary bone—Inner surface of the neck of the condyle of the inferior maxilla and the inter-articular fibro-cartilage.

Action of the Muscles which depress the Lower Jaw.—The most important of these muscles have for their fixed point of action the hyoid bone, which, under these circumstances, is fixed by the muscles which extend from it to the upper part of the chest. The central tendon of the digastric, as it per-

forates the stylo-hyoid, is connected with the hyoid bone by a loop of fibrous tissue; and acting from this bone as the fixed point, the anterior belly must of necessity tend to depress the jaw. The attachments of the mylo-hyoid and the genio-hyoid render their action in depressing the jaw sufficiently evident, which is also the case with the platysma myoides, acting from its attachments to the upper part of the thorax.

It has been a disputed question whether the upper jaw does or does not participate in the act of opening the mouth. That depression of the lower jaw is the main action in ordinary mastication is sufficiently evident; but it is possible, by fixing the lower jaw, to perform the acts of mastication —laboriously and imperfectly it is true—by movements of the upper jaw. In ordinary mastication, the upper jaw undergoes a slight movement of elevation in opening the mouth; and this becomes somewhat exaggerated when the mouth is opened to the fullest possible extent. Without citing the various authorities for and against this opinion, it will be sufficient, perhaps, to mention the following simple experiment, suggested to Monro by Pringle: "If," says he, "you place the blade of a knife or the finger nail in a situation which corresponds precisely with the point of contact of the teeth, when the mouth is closed, the knife being held in a fixed position during the time when the mouth is opened, it can be observed in a mirror that the upper teeth are sensibly elevated every time the mouth is opened."[1]

Many speculations have been put forward by those who adopt this view, as to the precise muscular action involved in this movement, which is necessarily a movement of the entire head. It is possible that the posterior belly of the digastric may have such an action, to a slight extent. The movement of the head, however, does not ordinarily require any powerful muscular action, and is probably the result of the contraction of muscles too deeply situated to be explored experimentally. It is evidently not due, as a rule, to

[1] Cited by Bérard, *Cours de Physiologie*, Paris, 1848, tome i., p. 617.

the contraction of those of the posterior muscles of the neck, which have for their chief function the elevation of the head.

Action of the Muscles which elevate the Lower Jaw, and move it laterally and antero-posteriorly.— The temporal, masseter, and internal pterygoid muscles are chiefly concerned in the simple act of closing the jaws. As this is almost the only movement of mastication in many of the carnivora, in this class of animals these muscles are most largely developed. Their anatomy alone gives a sufficiently clear idea of their mode of action; and their immense power, even in the human subject, is explained by the number of their fibres, by the attachments of many of these fibres to the strong aponeuroses by which they are covered, and the fact that the distance from their origin to their insertion is very short.

The attachments of the internal and external pterygoids are such that by their alternate action, on either side, the jaw may be moved laterally, as their points of origin are situated in front and within the temporo-maxillary articulation. As was first shown by Ferrein,[1] the articulation of the lower jaw is of such a nature that, in its lateral movements, the condyles themselves cannot be sufficiently displaced from side to side, but with the condyle on one side fixed or moved slightly backward, the other may be brought forward against the articular eminence, producing a movement of rotation. The pterygoid muscles are largely developed in the herbivora, in which the lateral movements of mastication are so important.

The above explanation of the lateral movements of the jaw presupposes the possibility of movements in an antero-posterior direction. Movements in a forward direction, so as to make the lower teeth project beyond the upper, are effected by the pterygoids, the oblique fibres of the masseter,

[1] FERREIN, *Mémoire sur les mouvements de la Mâchoire inférieure.—Mémoires de l'Acad. des Sciences*, Paris, 1744, p. 434.

with the anterior fibres of the temporal. By the combined action of the posterior fibres of the temporal, the digastric, mylo-hyoid, and genio-hyoid, the jaw is brought back to its position. By the same action it may also be drawn back slightly from its normal position while at rest.

Action of the Tongue, Lips, and Cheeks, in Mastication.—Experiments on living animals and phenomena observed in cases of lesions of the nervous system in the human subject have fully demonstrated the importance of the tongue and cheeks in mastication. The following observations of Panizza on the effects of section of both hypoglossal nerves in dogs show the importance of the tongue, both in mastication and deglutition: "After the section of the hypoglossal the movements of the tongue cease immediately, but the general sensibility of that organ and the taste was not less marked. Indeed, if milk, or bread moistened in the liquid, were presented to the dog, he made ineffectual efforts to lap and to masticate, moving the head and the lower jaw; the tongue, when displaced, remaining in the same position, and even when a bolus of meat or bread was put on its anterior surface, it was found for a long time after in the same place, which proves that section of the hypoglossals destroys not only the movements necessary to mastication, but also those of deglutition."[1] We have lately had occasion to verify most of these observations by Panizza in a dog in which both sublingual nerves were divided. The experiment, however, was made chiefly with reference to the action of the tongue in deglutition.

Section of the facial nerves is now a common physiological experiment; and operations of this kind, with cases of facial palsy, which are not uncommon in the human subject, show that when the cheek is paralyzed the food accumulates between it and the teeth, producing great inconvenience.

[1] PANIZZA, *Nouvelles Recherches Expérimentales sur les Nerfs.—Gazette Médicale de Paris*, 1835, p. 419.

In animals, like the herbivora, that use the lips and tongue extensively in the prehension of food, division of the facial and hypoglossal nerves interferes materially with this function.

The tongue is a muscular organ which, by virtue of the complex arrangement of its fibres, is capable of a great variety of important movements. Reference has already been made to the importance of these movements in suction. By the action of what are called the extrinsic muscles of the tongue, the organ is moved in various directions, while the intrinsic muscles are capable at the same time of producing many changes in its form. For example, by the action of those fibres of the genio-hyo-glossal muscles which are attached to the chin and the posterior part of the tongue, the whole organ is carried forward and may be protruded to a considerable extent. At the same time the whole length of the muscles may act upon the middle line of the tongue, to which they are attached, and depress the centre so as to render it concave from side to side; or the transverse fibres of the tongue may act so as to make it longer and narrower. The tongue is drawn into the mouth by the action of the anterior fibres of the genio-hyo-glossus on either side, and may be still further shortened by the contraction of the stylo-glossus, and the interior fibres of the hyo-glossus —its intrinsic and superior longitudinal fibres. The general action of the hyo-glossus, on either side, is to draw down the sides of the tongue and make it convex from side to side. The stylo-glossus and the palato-glossus draw the back of the tongue upward and backward toward the pharynx, and are thus useful in the first processes of deglutition. By the combined and varied actions of these and other muscles, the tongue is made to perform the numerous movements which take place in connection with phonation, suction, mastication, deglutition, etc.

The varied and complicated movements of the tongue during mastication are not easily described. After solid

food is taken into the mouth, the tongue prevents its escape from between the teeth; and, by its constant movements, rolls the alimentary bolus over and over, and passes it at times from one side to the other, so that it may undergo thorough trituration. Aside from functions of the tongue as an organ of taste, its surface is endowed with peculiar sensibility as regards the consistence, size, and form of different articles;[1] and this property is undoubtedly important in determining when mastication is completed; although the thoroughness with which mastication is accomplished is very much influenced by habit.

Tonic contraction of the orbicularis oris is necessary to keep the fluids in the mouth during repose; and this muscle is sometimes brought into action when the mouth is very full, to assist in keeping the food between the teeth. This latter function, however, is mainly performed by the buccinator; the action of which is to press the food between the teeth and keep it in place during mastication; assisting, from time to time, in turning the alimentary bolus so as to subject new portions to trituration.

The process of mastication is regulated to a very great extent by the exquisite sensibility of the teeth to the impressions of hard and soft substances. It is only necessary to call attention to the ease and certainty with which we recognize the presence and the consistence, even of the smallest substance between the teeth, in order to appreciate the advantages of this tactile sense in mastication. It is in this way, mainly, that we are notified when the process of mastication is completed; and it is this sense which admonishes us instantly of the presence of bodies too hard for mastication, which, if allowed to remain in the mouth, might seriously injure the teeth. Attention was called to these interesting facts by the late Dr. Graves, of Dublin, who says: "In truth, the teeth

[1] Every one is aware how readily a hair, or any minute substance, which would hardly be felt even by the ends of the fingers, is detected in the mouth; and how annoying the sensation is until the offending substance is removed.

may, in this point of view, be considered as a sort of fingers fixed within the mouth, destined to feel, examine, and adjust the morsel preparatory to placing it in the position most favorable to its mastication."[1] He further states that though this subject has engaged his attention for several years, he has observed no cases of paralysis in which this peculiar sensibility was affected.

In persons who use false teeth, the pressure on the gums in mastication takes the place imperfectly of the tactile sensibility of the natural teeth. The sensibility of the latter is dependent, undoubtedly, on the nerves distributed to the dental pulp.

Summary of the Process of Mastication.—The various muscles attached to the lower jaw are competent to bring the teeth together, and to produce a lateral movement and a movement backward and forward. Some articles of food are torn asunder by movements of the head and the upper extremities, as in the carnivora, or divided by the incisors, as in the herbivora. After the food is taken into the mouth, it is kept between the molars and subjected to their triturating action, which is effected by movements of opening and closing the jaws, conjoined with marked lateral movements. The position of the muscles and the peculiar construction of the temporo-maxillary articulation are such as to enable the condyles of the inferior maxilla, on either side, to alternately slide forward, producing rotation and deviation of the bone to the opposite side. In this movement, the condyle, covered by the pliable inter-articular fibro-cartilaginous disk, and thus presenting a concave articulating surface, is brought in contact with the articulating eminence in front of the glenoid cavity of the temporal bone.

Mastication should be continued until the alimentary bolus has become thoroughly triturated. The food, at the same time,

[1] GRAVES, *On a Peculiar Affection of the Nerves of the Teeth.—Dublin Journal of Medical Science*, 1836, vol. ix., p. 3.

becomes incorporated with the fluids of the mouth, particularly that poured out by the parotid glands, and entangles a considerable quantity of air. This preparation is important in insuring the prompt and efficient action of the gastric juice. It is less essential in the digestion of animal than of vegetable food, but still increases the facility of digestion of both. Many of the vegetable grains which are covered with a hard epidermis, when they escape the action of the teeth, are apt to pass through the alimentary canal unchanged, and may be recognized entire in the fæces. This fact with regard to the digestion of vegetable grains was proven, early in the history of the physiology of digestion, by the experiments of Spallanzani, who forced fowls and rooks to swallow small, perforated metallic tubes filled with beans and grains of wheat. When the grains were enclosed in these tubes entire, he found them but slightly swollen and softened after a number of hours' sojourn in the stomach; but when the grains were introduced slightly broken, they were found, in one experiment, to lose one-fourth of their weight in eight hours, and were at last entirely dissolved.[1] This fact was further confirmed by experiments on sheep, in which a number of tubes, some filled with herbs entire, and others with herbs which had been triturated, were introduced into the alimentary canal. At the end of thirty-three hours, five tubes were discharged by the anus. In two of these, in which the food had been introduced entire, the contents were apparently unchanged, but in the others, in which the food had been triturated, nothing remained but a small amount of indigestible matter.[2]

[1] SPALLANZANI, *Opuscules de Physique, Animale et Végétale*, Pavie, 1787, tome ii., p. 462.

[2] Ibid., p. 552.

CHAPTER VI.

INSALIVATION.

General considerations—Parotid saliva—Relations of the parotid secretion to mastication—Submaxillary saliva—Relations of the submaxillary secretion to mastication and gustation—Sublingual saliva—Fluids from the smaller glands of the mouth, tongue, and fauces—Mixed saliva—Quantity of saliva—General properties and composition of the saliva—Functions of the saliva—Action of the saliva on starch—Mechanical functions of the saliva.

One of the most important of the digestive processes which take place in the mouth is the incorporation of the saliva with the food, or insalivation. Not only has this fluid a mechanical function, assisting to reduce the food to the proper form and consistence to be easily swallowed, but it seems to be necessary to the proper performance of the subsequent processes of digestion, and is concerned to a considerable extent in the transformation of starch into sugar. That the saliva is necessary to digestion is proven by the grave effects upon the general function of nutrition which follow its loss in any considerable quantity. This occasionally occurs from the habit of excessive spitting, or as the result of salivary fistula. It becomes important, therefore, to study the physical and chemical properties of the saliva, the sources from which it is derived. and its mechanical and chemical functions in digestion.

Saliva.

The fluid which is mixed with the food in mastication, which moistens the mucous membrane of the mouth, and

which may be collected at any time in small quantity by the simple act of sputation, is composed of the secretions of a considerable number and variety of glands. The most important of these are the parotid, submaxillary, and sublingual, which are usually called the salivary glands, and, in addition, the labial and buccal glands, the follicular glands of the tongue and general mucous surface, and certain glandular structures in the mucous membrane of the pharynx. The liquid which becomes more or less incorporated with the food before it descends to the stomach, and which must be considered as the digestive fluid of the mouth, is known as the mixed saliva; but the study of the composition and properties of this fluid as a whole should be prefaced by a consideration of the different fluids of which it is composed.

The salivary glands belong to the variety of glands called racemose. They closely resemble the other glands belonging to this class, and their structure will be considered more particularly under the head of secretion.

Parotid Saliva.—The parotid is the largest of the three salivary glands. It is situated below and in front of the ear, and opens, by the duct of Steno, into the mouth at about the middle of the cheek. The papilla which marks the orifice of the duct is situated opposite the second large molar tooth of the upper jaw. Bernard, to whom belongs the credit of having established the general physiological distinctions between the different fluids which enter into the composition of the mixed saliva, cites Hapel de la Chenaie as the first to obtain the pure parotid saliva from the horse, by section of the duct of Steno, in 1780.[1] Tiedemann and Gmelin, in their work on digestion, recognized the distinction between the saliva found in the mouth, and the secretion of the parotid,

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 30. The original memoir by Hapel de la Chenaie (*Observations et Expériences sur l'analyse de la Salive du Cheval*), is published in the *Mémoires de la Société Royale de Médecine*, Paris, 178) and 1781, p. 325.

taken from the duct of Steno.[1] Numerous opportunities have presented themselves, in cases of salivary fistula, for the study of the properties of the pure parotid saliva in the human subject; and the situation of the duct of Steno, in the herbivora especially, is such that this fluid can easily be obtained by operations on the inferior animals. Prof. Dalton has obtained the pure parotid saliva from the human subject by simply introducing a silver tube, of from $\frac{1}{25}$ to $\frac{1}{20}$ of an inch in diameter, into the duct by its opening into the mouth.[2] In this way the fluid may be obtained with great facility and in absolute purity; and by this means, Prof. Dalton has developed many interesting facts connected with its function, beside confirming some of the important observations of Bernard, Colin, and others, on the inferior animals. The quantity thus obtained was considerable. In one observation, four hundred and eighty grains flowed from a tube introduced into the duct of Steno in the course of twenty minutes; and in seven successive observations, made on different days, comprising in all three hours and nine minutes, a little over three thousand grains were collected.[3]

[1] TIEDEMANN ET GMELIN, *Recherches Expérimentales Physiologiques et Chimiques sur la Digestion*, traduit par JOURDAN, Paris, 1827, tome i., p. 4 *et seq.*

[2] DALTON, *A Treatise on Human Physiology*, third edition, Philadelphia, 1864, p. 125 *et seq.*

[3] The saliva thus obtained was analyzed under the direction of Prof. Dalton by Mr. Maurice Perkins, Assistant to the Professor of Chemistry in the College of Physicians and Surgeons, New York (*op. cit.*, p. 126). A point to be remarked in this analysis is the large proportion of organic matter, which is several times greater than that given by others for the parotid, or even for the mixed saliva:

Composition of Human Parotid Saliva.

Water	983·308
Organic matter precipitable by alcohol	7·352
Substances destructible by heat, but not precipitated by alcohol or acids	4·810
Sulpho-cyanide of sodium	0·330
Phosphate of lime	0·240
Chloride of potassium	0·900
Chloride of sodium and carbonate of soda	3·060
	1,000·000

The following facts with regard to the properties of the parotid saliva observed by Dalton are given in his own words, in a communication kindly made in answer to certain inquiries:

"On the 28th of July, 1863, I obtained, from a strong, healthy man, about two drachms of the mixed saliva of the mouth, by causing him to hold in his mouth for a short time a clear glass stopper, and collecting the secretion as it was discharged.

"One hour afterward I obtained, from the same man, four drachms of pure parotid saliva, by introducing a long silver canula into the natural orifice of Steno's duct, on the left side, and collecting the saliva as it flowed from the outer extremity of the canula.

"The two kinds of saliva compared as follows:

"Both were distinctly alkaline in reaction; the parotid saliva rather the more so.

"The parotid saliva was rather clear and watery in appearance; the saliva of the mouth was quite opaline, with admixture of buccal epithelium, but became clear on filtration.

"The parotid saliva was rendered turbid by the action of heat, and by the addition of nitric acid, as well as sulphate of soda in excess; but not by sulphate of magnesia, nor by ferro-cyanide of potassium with acetic acid.

"The saliva of the mouth, filtered clear, became turbid by heat and by nitric acid; but showed no precipitate by either sulphate of soda or sulphate of magnesia in excess. There was also a slight precipitate on the addition of pure acetic acid, which did not take place in the parotid saliva.

"The parotid saliva showed no traces of sulpho-cyanogen on the addition of the perchloride of iron; but they were distinctly marked in the buccal saliva.

"On mixing the two kinds of saliva with boiled starch, and keeping the mixture at the temperature of 100° Fahr., sugar was present *in both specimens* at the end of five min-

utes. There was no marked difference between them in this respect.

"While making some similar experiments to the above on a previous patient, in April, 1863, I found that with the canula introduced into Steno's duct, not only was the discharge of parotid saliva increased by the mastication of food, but that it ran from the canula very much faster than in a state of rest, whenever the patient smiled, spoke, or moved his lips or cheeks in any way."

The organic matter of the parotid saliva is coagulable by heat (212° Fahr.), alcohol, and the strong mineral acids. Dalton found, in the human saliva, that it was also coagulated by an excess of sulphate of soda; but Bernard states that in the parotid saliva of the horse, the organic matter will pass through a mixture of sulphate of soda, but is coagulated by sulphate of magnesia.[1] Almost all physiologists agree that this organic matter is not identical in its properties with albumen, nor with the peculiar principle described by Mialhe in the mixed saliva, under the name of animal diastase.[2]

A compound of sulpho-cyanogen is now generally acknowledged to be a constant constituent of the parotid saliva. This cannot be recognized by the ordinary tests in the fresh saliva taken from the duct of Steno, but in the clear filtered fluid which passes after the precipitation of the organic matter, there is always a distinct red color on the addition of the persulphate of iron. As this reaction is more marked in the mixed saliva, the methods by which the presence of a sulpho-cyanide is to be demonstrated will be considered in connection with that fluid.

In the human subject, the parotid secretion is more abundant than that of any other of the salivary glands. The entire quantity in the twenty-four hours has not been directly

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 67.

[2] MIALHE, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 39.

estimated; but Prof. Dalton found that during mastication, the quantity secreted in twenty minutes on one side was 127·5 grains, and on the other side, 374·4 grains.

A curious fact with regard to the influence of mastication upon the flow from the parotids was observed by Colin in the horse, ass, and ox. He found that when mastication was performed on one side of the mouth, the flow from the gland on that side was greatly increased, exceeding by several times the quantity produced on the opposite side.[1] This fact was confirmed by Dalton, as already indicated, in the human subject.[2]

The flow of saliva from the parotid takes place with greatly increased activity during the process of mastication. The orifice of the parotid duct is so situated that the fluid is poured directly upon the mass of food as it is undergoing trituration by the teeth; and as the secretion is more abundant on the side on which mastication is going on, and as the consistence of the fluid is such as to enable it to mix readily with the food, the function of this gland is supposed to be particularly connected with mastication. This is undoubtedly the fact; though its flow is not absolutely confined to the period of mastication, but continues, in small quantity, in the intervals. Its quantity is regulated somewhat by the character of the food, being much greater when the articles taken into the mouth are dry than when they contain considerable moisture. Colin has shown in some of the herbivora a remarkable insensibility of the parotids to the stimulus of sapid and aromatic substances applied to the mucous membrane of the cheeks. In the ruminants, in which there is a constant flow from these glands, the quantity cannot be increased by the action of salts, feeble acids, or aromatic substances.[3] The experiments of Bernard on dogs show a cer-

[1] Colin, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1854, tome i., p. 468.

[2] *Loc. cit.*

[3] *Op. cit.*, p. 471.

tain increase in the flow of saliva from a tube introduced into the duct of Steno, on the application of vinegar to the mucous membrane of the mouth; but this was slight as compared with the increase in the flow of the submaxillary secretion.[1] There is, in fact, a great difference in different animals as regards the excitability of the salivary glands by substances introduced into the mouth. In the human subject, the excitation produced by sapid substances will sometimes induce a great increase in the flow of the parotid saliva. Mitscherlich and Eberle[2] observed this in persons suffering from salivary fistula, and noted, furthermore, that the mere sight or odor of food produced the same effect. Magendie mentions a case in which the sight of food produced such an effect that the saliva was discharged from the duct to the distance of several feet.[3]

The supposition, which has been entertained by some authors, that the flow from the parotid is dependent upon the mechanical pressure of the muscles or of the condyle of the lower jaw during mastication has no foundation in fact. It is now well established that one of the indispensable conditions in the production of a secretion is a great increase in the quantity of blood circulating in the gland, and that the vascular supply is regulated through the nervous system. It is not rational to suppose that the parotid is an exception to this rule; and Bernard has shown that galvanization of the small root of the fifth pair of nerves and of the facial immediately produces an intense parotid secretion.[4] The fact that an alternation in the parotid secretion accompanies an alternation in the act of mastication is also an argument against this mechanical theory; for it is not to be supposed that

[1] BERNARD, *Leçons sur les Propriétés, etc., des Liquides de l'Organisme*, Paris, 1859, tome ii., p. 250 *et seq.*

[2] MITSCHERLICH, *Ueber den Speichel des Menschen.—Poggendorff's Annalen der Physik und Chemie*, 1833, Bd. xxvii., S. 328.

[3] MAGENDIE, *Précis Elémentaire de Physiologie*, Paris, 1836, tome ii., p. 56.

[4] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 69.

during mastication there exists a difference in the pressure of the muscles or of the condyles on the two sides, corresponding with the differences which have been noted in the secretion from the glands on either side. In the horse and in the dog, it has been observed that the secretion of the parotids is completely arrested during the deglutition of liquids, while the flow from the other salivary glands is not affected.[1]

To sum up the functions of the parotid saliva,—aside from any chemical action which it may have upon the food, which will be fully considered in connection with the mixed saliva,—it evidently has an important mechanical office. It is discharged in large quantity during the entire process of mastication, and is poured into the mouth in such a manner as to become of necessity thoroughly incorporated with the food. Its function is chiefly, though not exclusively, connected with mastication, and indirectly with deglutition; for it is only by becoming incorporated with this saliva, that the deglutition of dry pulverulent substances is rendered possible. Facts in comparative physiology, showing a great development of the parotids in animals that masticate very thoroughly, particularly the ruminants, a slight development in those that masticate but slightly, and the absence of these glands in animals that do not masticate at all,[2] are additional arguments in favor of these views.

Submaxillary Saliva.—In the human subject, the submaxillary is the second of the salivary glands in point of size. Its minute structure is the same as that of the parotid. As its name implies, it is situated below the inferior maxillary bone, and is found in the anterior part of what is known as the submaxillary triangle of the neck. Its excretory duct, called sometimes the duct of Wharton, is about two inches

[1] BERNARD, *op. cit.*, p. 52.

[2] MILNE-EDWARDS, *Leçons sur la Physiologie et l'Anatomie Comparée*, Paris, 1859, tome vi., p. 239.

in length, and passes from the gland, beneath the tongue, to open by a small papilla by the side of the frenum. This gland is relatively very small in the herbivora, but is largely developed in the carnivora; in the latter being larger than the parotid.

The pure submaxillary saliva presents many important points of difference from the secretion of the parotid. It was first studied as a distinct fluid by Bernard. It may be obtained by exposing the duct and introducing a fine silver tube, when on the introduction of any sapid substance into the mouth, the secretion will flow in large pearly drops. Bernard found this variety of saliva much more viscid than the secretion from the parotid. It is perfectly clear, and, on cooling, frequently becomes of a gelatinous consistence.[1] Its organic matter is not coagulated by heat. In the dog it is rather more strongly alkaline than the parotid saliva. According to Bernard, it does not contain the sulpho-cyanide of potassium.[2]

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 72. The late experiments of Bernard concerning the influence of the nervous system on secretion were made chiefly on the submaxillary gland. These points will be fully considered under the head of Secretion.

[2] BIDDER AND SCHMIDT give the following as the result of two analyses of the submaxillary saliva:

First Analysis.

Water	996·04
Organic matter	1·51
Inorganic matter	2·45
	1,000·00

Second Analysis.

Water		991·45
Organic matter		2·89
Inorganic matter	Chloride of calcium, Chloride of sodium	4·50
	Carbonate of lime, Phosphate of lime, Phosphate of magnesia	1·16
		1,000·00

—*Die Verdauungssäfte*, Leipzig, 1852, S. 8.

The submaxillary gland pours out its secretion in greatest abundance when sapid substances are introduced intc the mouth. Bernard is of the opinion that the function of this gland is connected exclusively with gustation, and that secretion never takes place except in obedience to stimulation of the gustatory nerves.[1] It is undoubtedly true that the most marked influence of sapid substances is upon the submaxillary gland, and that this is the case in dogs has been sufficiently proven by experiments. In the solipeds and ruminants, Colin has observed that the quantity of submaxillary saliva secreted is much increased during eating; but, unlike the parotids, the secretion does not alternate on the two sides with the alternation in mastication. He has found in all the domestic animals, that the flow is greatly influenced by the degree of sapidity of the food.[2] As regards the special functions of the different salivary glands, it is impossible to reason directly from the inferior animals to the human subject; and the distinction which Bernard has endeavored to establish between the different glands is undoubtedly too rigorous. Although sapid articles induce an abundant secretion from the submaxillary glands, they also produce an increase in the secretions from the parotids and sublinguals; and, on the other hand, movements of mastication increase somewhat the flow from the submaxillaries, and these glands secrete a certain amount of fluid during the intervals of digestion. The viscid consistence of the submaxillary saliva renders it less capable of penetrating the alimentary mass during mastication than the parotid secretion, so that it remains chiefly on or near the surface of the bolus.

Sublingual Saliva.—The sublinguals, the smallest of the salivary glands, are situated beneath the tongue, on ei-

[1] *Op. cit.*, p. 85.

[2] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1854, tome i., p. 473.

ther side of the frenum. In minute structure they resemble the parotid and the submaxillary glands. Each gland has a number of excretory ducts, from eight to twenty, which open into the mouth by the side of the frenum; one of the ducts, larger than the others, joins the duct of the submaxillary gland near its termination in the mouth.

The secretion of the sublingual glands is more viscid even than the submaxillary saliva; but it differs in the fact that it does not gelatinize on cooling. It is so glutinous that it adheres strongly to any vessel, and flows with difficulty from a tube introduced into the duct. Like the secretion from the other salivary glands, its reaction is distinctly alkaline. Its organic matter is not coagulated by heat, acids, nor the metallic salts. According to Bernard, after desiccation it is redissolved by water, and its viscid properties are then restored.[1]

In accordance with the view entertained by Bernard concerning the function of this variety of saliva and its special connection with deglutition, it is supposed to be secreted immediately before and during the act of swallowing. The experiments which are advanced in support of this view are mostly those in which a tube was fixed in each of the three salivary ducts in a dog; when the animal was caused to make movements of the jaw, movements of deglutition, and at the same time the gustatory nerves were stimulated by the introduction of vinegar into the mouth. In an experiment of this kind, it was observed that fluid was secreted by all the glands, but in unequal proportions; "the submaxillary saliva flowed very abundantly, the parotid saliva much less, and the sublingual saliva flowed very feebly."[2] Although the

[1] BERNARD, *op. cit.*, p. 92.

Bernard gives a table of the composition of the sublingual saliva taken from Bidder and Schmidt. This is an error. The table referred to is the composition of the mucous secretion of the mouth (*Mundschleim*); and the authors referred to only analyzed, as distinct secretions, the parotid and sublingual saliva, the compositions of which have been given. (*Die Verdauungssäfte*, etc., S. 5.)

[2] BERNARD, *op. cit.*, p. 81.

animal made movements of mastication, experienced a gustatory impression, and made movements of deglutition, it is by no means evident from this observation, nor from others reported by Bernard, that the flow of the sublingual saliva had any special connection with the act of deglutition. The observations of Colin on this subject show that in the domestic ruminants, there is a constant flow of the sublingual saliva during the time occupied in eating.[1]

It has been experimentally demonstrated that the sublingual glands may be excited to secretion by impressions made by sapid substances upon the nerves of taste, though the flow is always less than from the submaxillary glands. The great viscidity of the sublingual saliva renders it less easily mixed with the alimentary bolus than the secretions from the parotid or submaxillary glands.

Fluids from the Smaller Glands of the Mouth, Tongue, and Pharynx.—Beneath the mucous membrane of the inner surface of the lips, are small, rounded glandular bodies, opening by numerous ducts into the buccal cavity, called the labial glands; and in the submucous tissue of the cheeks, are similar bodies, called the buccal glands. The latter are somewhat smaller than the labial glands. Two or three of the buccal glands are of considerable size, and have ducts opening opposite the last molar tooth; and these are sometimes distinguished as the molar glands. There are also a few small glands in the mucous membrane of the posterior half of the hard palate; but the glands on the under surface of the soft palate are larger and more numerous, and here form a continuous layer. The glands of the tongue (lingual glands) are situated beneath the mucous membrane, mainly on the posterior third of the dorsum; but a few are found at the edges and the tip. All of these are small racemose glands, similar in structure to those which have been called the true salivary

[1] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1854, tome I., p. 483.

glands. In addition to these structures, the mucous membrane of the tongue is provided with a number of simple and compound follicular glands, which extend over its entire surface, but are most abundant at the posterior portion, behind the circumvallate papillæ.

In the pharynx and the posterior portion of the buccal cavity, are found the pharyngeal glands and the tonsils. In the pharynx, particularly the upper portion, racemose glands, like those found in the mouth, exist in large numbers. The mucous membrane is provided, also, with numerous simple and compound mucous follicles. The tonsils, situated on either side of the fauces between the pillars of the soft palate, consist of an aggregation of compound follicular glands, held together by fibrous tissue. The number of glands entering into the composition of each tonsil is from ten to twenty.[1]

The secretion from the glands and follicles above enumerated cannot be obtained, in the human subject, unmixed with the fluids from the true salivary glands. It has been obtained, however, in small quantity, from the inferior animals, after ligation of all the salivary ducts. This secretion is simply a grayish, viscid mucus, containing a number of leucocytes and desquamated epithelial scales. It is this which gives the turbid and opaline character to the mixed saliva, as the secretions of the various salivary glands are all perfectly transparent. The fluid from these glands in the mouth is mixed with the salivary secretions; and that from the posterior part of the tongue, the tonsils, and the pharyngeal glands passes down to the stomach with the alimentary bolus. This secretion consequently forms a constant and essential part of the mixed saliva.

Mixed Saliva.—Although the study of the distinct secretions discharged into the mouth possesses considerable physi-

[1] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 284.

ological interest and importance, it is only the fluid resulting from a union of them all, which can properly be considered in connection with the general process of insalivation. In man it is necessary that the cavity of the mouth should be continually moistened, if for nothing else, to keep the parts in a proper condition for phonation. A little reflection will make it apparent that the flow, from some of the glands at least, is constant, and that from time to time a certain quantity of saliva is swallowed. This is even more marked in some of the inferior animals, as the ruminants. The discharge of fluid into the mouth, though diminished, is not arrested during sleep. In the review of the different kinds of saliva, it has been seen that the flow from none of the glands is absolutely intermittent; unless, occasionally, from the parotid, the secreting function of which is most powerfully influenced by the act of mastication and the impression of sapid substances.

Upon the introduction of food, the quantity of saliva is enormously increased; and we have already noted the influence of the sight, odor, and occasionally even the thought of agreeable articles. Many persons present a marked increase in the flow of saliva at the sight of a lemon; and we are all familiar, in a general way, with the impressions which bring "water into the mouth."[1] The experiments of Frerichs on dogs with gastric fistulæ,[2] and the observations of Gardner on a patient with a wound in the œsophagus,[3] have demonstrated that the flow of saliva may be excited by the stimulus of food introduced directly into the stomach without passing

[1] COLIN (*op. cit.*, p. 471) has failed to excite the salivary secretion in the horse by the sight of food; but the fact with regard to the human subject has been repeatedly noted by physiologists.

[2] FRERICHS, *Die Verdauung.*—WAGNER'S *Handwörterbuch der Physiologie*, Braunschweig, 1846, Bd. iii., S. 759.

[3] GARDNER, *Case of a Wound of the Throat in which the Trachea and Œsophagus were divided across, and which did not terminate fatally, although the parts have not reunited.—Edinburgh Medical and Surgical Journal*, 1820, vol. xvi., p. 358.

through the mouth. It is well known that the quantity of saliva may be increased by directing the attention to this secretion, moving the tongue about in the mouth, sucking the cheeks, and discharging the fluid by sputation; and it may be largely increased by taking into the mouth glass beads, pebbles, or smooth articles of this kind.

Quantity of Saliva.—It is not easy to estimate, in the human subject, the entire quantity of saliva secreted in the twenty-four hours; and great variations in this regard undoubtedly exist in different persons, and even in the same individual at different times. An approximate estimate may be arrived at by noting, as nearly as possible, the average quantity secreted during the intervals of digestion, and adding to it the quantity absorbed by the various articles of food. Some of the earlier physiologists investigated this subject with much patience. Bérard quotes the experiments of Siebold, who collected the saliva by holding the mouth open with the head inclined so that the fluid should flow into a vessel as fast as secreted.[1] An estimate of this kind can only be approximative; and those made by Dalton are apparently the most satisfactory. This observer found that he was able to collect from the mouth, without any artificial stimulus, about five hundred and fifty-six grains of saliva per hour; and he also found that wheaten bread gained in mastication fifty-five per cent., and lean meat forty-eight per cent. in weight. Assuming the daily allowance of bread to be nineteen ounces, and the allowance of meat to be sixteen ounces, and estimating the quantity of saliva secreted during twenty-two hours of interval, the entire quantity in twenty-four hours would amount to 20,164 grains, or a little less than three pounds avoirdupois, of which rather more than one-half is secreted during the intervals of eating.[2]

Remembering that the quantity of saliva must necessarily

[1] *Op. cit.*, tome i., p. 696.

[2] DALTON, *A Treatise on Human Physiology*, Philadelphia, 1864, p. 128.

be subject to great variations, this estimate may be taken as giving a sufficiently close approximation of the quantity of saliva ordinarily secreted. It must be borne in mind, how ever, with reference to this and the other digestive secretions, that this immense quantity of fluid is at no one time removed from the blood, but is reabsorbed nearly as fast as secreted, and that normally, none of it is discharged from the organism

General Properties and Composition of Saliva.—The mixed fluid taken from the mouth is colorless, somewhat opaline, frothy, and slightly viscid. It generally has a faint and somewhat disagreeable odor very soon after it is discharged. If it be allowed to stand, it deposits a whitish sediment composed mainly of desquamated epithelial scales, with a few leucocytes; leaving the supernatant fluid tolerably clear. Its specific gravity is variable; ranging from 1,004 to 1,006 or 1,008. Its reaction is almost constantly alkaline; though, under certain abnormal conditions of the system, it has occasionally been observed to be neutral, and sometimes, though rarely, acid. We have occasionally observed a distinctly acid taste in the saliva after very severe, prolonged, and exhaustive muscular exertion. The saliva becomes slightly opalescent by boiling and on the addition of the strong acids. The addition of absolute alcohol produces an abundant, whitish, flocculent precipitate. Almost invariably the mixed saliva presents a more or less intense blood-red tint on the addition of a per-salt of iron, which is due to the presence of a sulpho-cyanide, either of potassium or sodium.

A number of analyses of the human mixed saliva have been made by different chemists, presenting, however, few differences, except in the relative proportions of water and solid ingredients, which are probably quite variable. One of the most recent of these analyses is the following by Bidder and Schmidt:[1]

[1] BIDDER UND SCHMIDT, *Die Verdauungssäfte*, Leipsig, 1852, S. 11.

Composition of Human Saliva.

Water	995·16
Epithelium	1·62
Soluble organic matter	1·34
Sulpho-cyanide of potassium	0·06
Phosphates of soda, lime, and magnesia	0·98
Chloride of potassium / Chloride of sodium	0·84
	1,000·00

The organic principle of the mixed saliva, called by Berzelius ptyaline, is not affected by heat or the acids, but on the addition of an excess of absolute alcohol, is coagulated in the form of whitish flakes, which may be readily separated by filtration. This substance has been closely studied by Mialhe, and is described by him under the name of animal diastase. This author regards it as the active principle of the saliva. It is obtained from the human saliva by the following simple process:

The fluid from the mouth is first filtered, then treated with five or six times its weight of absolute alcohol, by which a white or grayish-white precipitate is formed. This substance is collected on a filter, and is dried in thin layers on a plate of glass in a current of air at from 100° to 120° Fahr. It may then be preserved indefinitely in a well-stoppered bottle.[1] The principle thus prepared may be dissolved in water, when it is insipid, neutral, and becomes readily decomposed, giving rise to a substance resembling butyric acid. It has no influence upon the nitrogenized alimentary principles, but when brought in contact with raw or hydrated starch, readily transforms it, first into dextrine, and afterward into glucose. According to Mialhe, the energy of this action is such that one part is sufficient to effect the transformation of more than two thousand parts of starch.

The presence of a certain quantity of sulpho-cyanide of

[1] MIALHE, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 43.

potassium in the mixed saliva can be demonstrated by the addition of a per-salt, especially the perchloride, of iron. That this is a constant and normal ingredient of the human saliva cannot be doubted. We have frequently had occasion to apply this test to the saliva of different persons, and the results have been invariably the same. The peculiar reaction of the saliva with the perchloride of iron was first noticed by Treviranus, who called the substance producing it blood-acid. At the time this observation was made (1814), sulpho-cyanic acid had not been described. Tiedemann and Gmelin confirmed this observation, and demonstrated the presence of a sulpho-cyanide by other tests.[1]

It has been a question whether the red color produced by the perchloride of iron be really due to the presence of a sulpho-cyanide in the saliva; or, if it exist at all, whether this salt be a normal constituent, or be developed accidentally as a pathological condition, or produced, as has been suggested, by the action of reagents. The elaborate investigations of Longet seem to have settled these questions conclusively. He obtained nearly three quarts of human saliva, which he collected in half an hour from forty soldiers, fasting, who, after having rinsed and cleaned the mouth, excited the secretion by chewing pieces of India rubber. The fluid was then concentrated so that all the sulpho-cyanide was brought into a few drops, which showed, to an intense degree, the peculiar reaction with the perchloride of iron. By suitable manipulations, the presence of sulphur was also established.[2]

[1] TIEDEMANN ET GMELIN, *Recherches Expérimentales, Physiologiques et Chimiques sur la Digestion*, Paris, 1827, première partie, p. 9 *et seq.*

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 160. In these manipulations, Longet followed the process of Tiedemann and Gmelin (*loc. cit.*), whose observations on this point were simply confirmed; the difference being that in the observations of Longet the extract was made from a very large quantity of saliva. It is unnecessary to review the process by which it is demonstrated that the reaction with the perchloride is not due to the presence of the acetate of soda, as has been suggested.

Longet states, furthermore, that he has examined the saliva from a great number of persons, under all conditions, and has never failed to demonstrate the presence of the sulpho-cyanide. Its proportion he found very variable, and in some cases it was so slight that the reaction with the perchloride of iron did not immediately manifest itself; but by slowly evaporating the liquid to one-half or one-third of its original volume, the reaction became manifest in all cases.[1]

In examining the saliva of a number of persons, Bernard found some in which no red color was produced by the addition of the perchloride of iron, and he remarked that all in which the reaction was manifested were in the habit of smoking. This led him to add a little nicotine to the specimens of saliva which did not present this reaction, when a red color, somewhat less intense than in the other specimens, was produced.[2] If, in these experiments, the saliva had been slightly evaporated, it is probable that the reaction would have been manifested. We have frequently demonstrated to a medical class the presence of a sulpho-cyanide in the saliva of persons who had never used tobacco.

It is probable that the sulpho-cyanide of potassium is a constant ingredient of each of the three varieties of saliva. It has been found in the parotid, in cases of salivary fistula, and was noted by Dalton in the saliva taken from the duct of Steno, though in this case the saliva contained an organic principle which interfered with the test, but which could be precipitated by alcohol and separated by filtration.[3] Longet found the sulpho-cyanide in the saliva from the sub-

[1] Longet found the perchloride of iron a much more delicate test than the persulphate, which is sometimes used. When the peculiar reaction shows itself after evaporating the liquid, it is not due to mere concentration, but to some change which occurs during the process; for the color may be obtained when the quantity of water lost by evaporation has been restored. (BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, tome ii., p. 140.)

[2] BERNARD, *Liquides de l'Organisme*, Paris, 1859, tome ii., p. 244.

[3] See p. 157 (note). The analysis of Mr. Perkins gives the sulpho-cyanide of sodium instead of the sulpho-cyanide of potassium.

maxillary and sublingual glands, taken from the floor of the mouth behind the inferior incisor and canine teeth.[1]

Very little need be said concerning the remaining inorganic constituents of saliva, except that they are of such a nature as almost invariably to render the fluid distinctly alkaline. They exist in small proportion, and do not appear to be connected in any way with the functions of the saliva as a digestive fluid.

Functions of the Saliva.

Physiologists are not entirely agreed concerning some of the most important questions relating to the function of the mixed saliva in digestion. Bernard, from observations on the lower animals, particularly on dogs, concludes that the operation of the saliva is only mechanical; while others, in view of its property of rapidly transforming starch into sugar, attribute to it an important chemical function. The experiments on which the view of Bernard is based are conclusive, so far as they go. He has shown that none of the distinct varieties of saliva from the dog affect starch; that a mixture of the fluids from the three salivary glands is likewise inoperative; and that the mixed saliva from the mouth of the dog, containing the secretion of the mucous glands of the mouth, converts starch into sugar with difficulty. On the same page, however, he mentions the well-known fact that the human mixed saliva changes starch into sugar with great rapidity,[2] and that the same effect is produced by the unmixed parotid or submaxillary secretion.[3] In the dog, amylaceous principles taken by the mouth are always found unaltered in the stomach, and are only transformed into sugar in the small intestines; but observations have shown that this is not the case in the human subject. These facts are a sufficient argument against the direct appli-

[1] LONGET, *op. cit.*, p. 162.

[2] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 157 *et seq.*

[3] Ibid., p. 165.

cation of experiments made on an exclusively carnivorous animal, like the dog, to the digestive process in man. While there is no reason to suppose that there is any material difference in the mammalia, as regards the general operation of some of the functions, such as circulation or respiration, it is evident that differences exist in the properties of the digestive fluids, as well as in the teeth and jaws, corresponding with the great differences in the character and conditions of the alimentary principles. In the study of digestion, therefore, the results of experiments on the inferior animals cannot always be taken without reserve, and must be confirmed by observations on the human subject; but fortunately, the properties of nearly all of the digestive fluids which have been studied minutely by vivisections have been investigated more or less fully in man.

In 1831, Leuchs discovered that hydrated starch, mixed with fresh saliva and warmed, became liquid in the space of several hours and was converted into sugar.[1] This fact has since been repeatedly confirmed; and it is now a matter of common observation that hydrated starch, or unleavened bread, taken into the mouth, almost instantly loses the property of striking a blue color with iodine, and responds to the usual tests for sugar. Of the rapidity of this action any one can easily convince himself by the simple experiment of taking a little cooked starch into the mouth, mixing it well with the saliva, and testing in the ordinary way for sugar. This can hardly be done so rapidly that the reaction is not manifested; and the presence of sugar is also indicated by the taste. Though the human mixed saliva will finally exert the same action on uncooked starch, the transformation takes place much more slowly. It has been shown by experiment that all the varieties of human saliva have the same effect on starch as the mixed fluids of the mouth. Dalton found no difference in the pure parotid saliva and the mixed saliva of the human subject as regards the power of transforming starch into su-

[1] BURDACH, *Traité de Physiologie*, Paris, 1841, tome ix., p. 265.

gar.[1] Bernard obtained the pure secretions from the parotid and from the submaxillary glands in the human subject, by drawing it out of the ducts as they open into the mouth, with a small syringe with the nozzle arranged so as to fit over the papillæ, and demonstrated their action on starch.[2] This fact, with regard to the parotid, had previously been established in a patient with a fistula into the duct of Steno by Jarjavay and Mialhe, the experiment having been made at the suggestion of M. Bérard.[3] In this case the fluid from the fistula transformed starch into sugar with great facility. Longet afterward showed that a mixture of the secretions of the submaxillary and the sublingual glands had the same property.[4]

It is unnecessary, in this connection, to recite the numerous experiments on the influence of the saliva of the inferior animals on starch; but it may be stated, as an established and generally accepted fact, that the mixed saliva and the secretion of the different salivary glands, in the human subject, invariably transform cooked starch into sugar with great rapidity in the mouth, and also, at the proper temperature, out of the body. It has been also shown by Mialhe that the starch, though it is converted rapidly into sugar in this process, is first transformed into dextrine.[5]

This point being settled, there arises the important question whether the action of the saliva be really important in the digestion of starch, or whether this transformation be merely accidental; for it has been shown that other fluids,

[1] See page 159.

[2] *Loc. cit.*

[3] Bérard, *Cours de Physiologie*, Paris, 1849, tome ii., p. 403, note.

In many cases of salivary fistula, the fluid discharged failed to effect the transformation of starch. In the observations of Prof. Dalton on the parotid saliva taken from the duct by a tube introduced by the mouth, the transformation was complete. (Verbal communication.)

[4] Longet, *Traité de Physiologie*, Paris, 1861, tome i., p. 171.

[5] Mialhe, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 40.

among which may be mentioned the serum of the blood, the fluid found in cysts, and mucus, have the same property; although none, except the intestinal juices, are nearly so efficient as the saliva. And again, the quantity of starch contained in the food is so great that it would require, apparently, a longer contact with the saliva than usually takes place in the mouth to make this action very effective. These considerations make it necessary to follow the amylaceous principles of food into the stomach, and ascertain, if possible, whether the transformation into sugar be continued in this organ.

Bernard, after feeding a dog with starch, drew off the contents of the stomach by a gastric fistula, and found the starch unchanged, with no traces of sugar.[1] This experiment we have often repeated in public demonstrations, with the same results; but the differences already noted in the properties of the saliva of the human subject and of the inferior animals destroy much of the value of this observation. Longet[2] and others have shown that the addition of gastric juice to the saliva does not interfere with the action of the latter on starch, but it has been found that the reaction of the sugar thus resulting from the transformation of the starch is masked by the presence of other principles contained in the stomach. The question of the continuance, in the stomach, of the digestion of starch by the saliva is settled by the following observation by Grünewaldt and Schrœder, in 1853, on a woman with a gastric fistula:[3]

"After a meal of *raw starch*, no sugar was found in the contents of the stomach, the acid juice was drawn by the fistula, and was mixed with paste; the transformation into sugar commenced immediately. As Bidder has observed, the transforming property of the saliva persists, even in the presence of free acids.

"A few ounces of starch swelled with boiling water were

[1] *Op. cit.*, p. 159.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 173.

[3] Cited by LONGET, *op. cit.*, p. 174.

introduced in the stomach, fasting, by the fistula; immediately after, a portion of the starch was expelled again; already it contained sugar. A quarter of an hour after, a great deal of sugar was found in the stomach, and the paste had become entirely fluid."

There can be no doubt that the saliva, in addition to its important mechanical functions, transforms a considerable portion of the cooked starch, which is the common form in which this principle is taken by the human subject, into sugar; but it is by no means the only fluid engaged in its digestion, similar properties belonging, as we shall see hereafter, to the pancreatic and the intestinal juice. The last-named fluids are probably more active, even, than the saliva. The saliva acts slowly and imperfectly on raw starch, which is hydrated in the stomach and digested mainly by the fluids of the small intestine. In all probability, the saliva does not digest all the hydrated starch taken as food; the greater part passing unchanged from the stomach into the intestine. Those who attribute only a mechanical function to the saliva draw their conclusions entirely from experiments on the lower animals, particularly the carnivora; and it is evident that such observations cannot be strictly applied to the human subject.[1]

The principle which is specially active in the digestion of

[1] In the herbivora, the chemical action of the saliva is much more important than in the carnivora. In the report of a commission of the Academy of Sciences, in 1845, composed of Magendie, Rayer, Payen, and others, the following interesting facts were developed concerning the mixed saliva of the horse:

"This saliva was obtained in a state of purity by causing a horse, that had an opening into the œsophagus, to eat bran washed, first with cold water, and afterward with boiling distilled water. * * * *

"The bran thus prepared was given to the horse, who chewed it, moistened it with saliva, and swallowed it; and it is the liquid pressed from the masses and filtered which has been studied under the name of the mixed saliva. * *

"Like the human saliva taken from the mouth, the mixed saliva of the horse transforms starch-paste instantly into sugar at 104° Fahr. At the temperature of 104,° it has a slow but sensible action on raw starch and on coagulated albumen."—*Comptes Rendus*, Paris, 1845, pp. 903, 904.

starch, in the human subject at least, must exist in the pure secretion from the various glands, as well as in the mixed saliva. It has been isolated and studied by Mialhe, under the name of *animal diastase.* Its properties and its action on starch have already been noted in treating of the composition of the mixed saliva.

In treating of the various fluids which are combined to form the mixed saliva, their mechanical functions have necessarily been touched upon. To sum up this subject, however, it may be stated that the fluids of the mouth and pharynx have quite as important an office in preparing the food for deglutition and for the action of the juices in the stomach, as in the digestion of starch. Indeed, the former is probably the more important function in man and the herbivora. It is a matter of common experience that the rapid deglutition of very dry articles is impossible; and the experiments of Bernard and others on horses furnish very striking illustrations of the importance of the saliva as a purely mechanical agent. In the human subject, though mastication and insalivation are by no means so complete as in some of the lower animals, the quantity of saliva absorbed by the various articles of food is enormous. The observations of Dalton, which have been already referred to in treating of the entire quantity of saliva, show that white bread absorbs in the mouth fifty-five per cent., and cooked meat, forty-eight per cent. of its original weight.[1] It seems impossible that the fluid thus incorporated with the alimentary principles should not have an important influence on the changes which take place in the stomach, though it must be confessed that our information on this point is very meagre, except as regards the digestion of starch.

It is undoubtedly the abundant secretion of the parotid glands which becomes most completely incorporated with the food during mastication, and serves to unite the dry particles into a single coherent mass. In an experiment on a

[1] *Op. cit.*, p. 128.

horse, Bernard found that after the ducts of Steno had been divided, the portions of food, which were collected by an opening into the œsophagus as they were swallowed, were not coherent and were passed into the stomach with great difficulty. The time occupied in eating about three-quarters of a pound of oats was twenty-five minutes; while before the section of the salivary ducts, a pound of oats was eaten in nine minutes.[1]

The secretions from the submaxillary and sublingual glands and the small glands and follicles of the mouth, being more viscid and less in quantity than the parotid secretion, penetrate the alimentary bolus less easily, and have rather a tendency to form a glairy coating on its exterior; agglutinating the particles on the surface with peculiar tenacity.

When the process of mastication and insalivation is completed, and the food is passed back into the pharynx, it meets with the secretion of the pharyngeal glands, which still further coats the surface with the viscid fluid which covers the mucous membrane in this situation, thus facilitating the first processes of deglutition.

It has been observed that the saliva has a remarkable tendency to entangle bubbles of air in the alimentary mass. In mastication, a considerable quantity of air is mixed with the food, and this undoubtedly facilitates the penetration of the gastric juice. It is well known that moist, heavy bread, and articles that cannot become impregnated in this way with air, are not easily acted upon in the stomach.

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 146.

CHAPTER VII.

DEGLUTITION.

Physiological anatomy of the parts concerned in deglutition—Pharynx—Muscles of the pharynx—Muscles of the soft palate—Mucous membrane of the pharynx—Œsophagus—Mechanism of deglutition—First period of deglutition—Second period of deglutition—Protection of the posterior nares during the second period of deglutition—Protection of the opening of the larynx—Function of the epiglottis—Study of deglutition by auto-laryngoscopy—Third period of deglutition—Intermittent contraction of the lower third of the œsophagus—Nature of the movements of deglutition—Deglutition of air.

Deglutition.

DEGLUTITION is the act by which solid and liquid articles are forced from the mouth into the stomach. The process involves first, the passage—by a voluntary movement—of the alimentary mass through the isthmus of the fauces into the pharynx; then a rapid contraction of the constrictors of the pharynx, by which it is forced into the œsophagus; and, finally, a peristaltic action of the muscular walls of the œsophagus extending from its opening at the pharynx to the stomach.

Physiological Anatomy of the Parts concerned in Deglutition. — The parts concerned in this function are the tongue, the muscular walls of the pharynx, and the œsophagus. In the passage of food and drink through the pharynx, it is necessary to completely protect from the entrance of foreign matters a number of openings which are exclusively for the passage of air. These are the posterior

nares and the Eustachian tubes, above; and below, the opening of the larynx. The mechanism by which these passages are closed during the acts of deglutition is one of the most interesting subjects connected with this function, and has long engaged the attention of physiologists.

The tongue—a muscular organ capable of a great variety of movements, and endowed, as we have seen, with highly important functions connected with mastication—is the chief agent in the first processes of deglutition. Its physiological anatomy has already been considered.

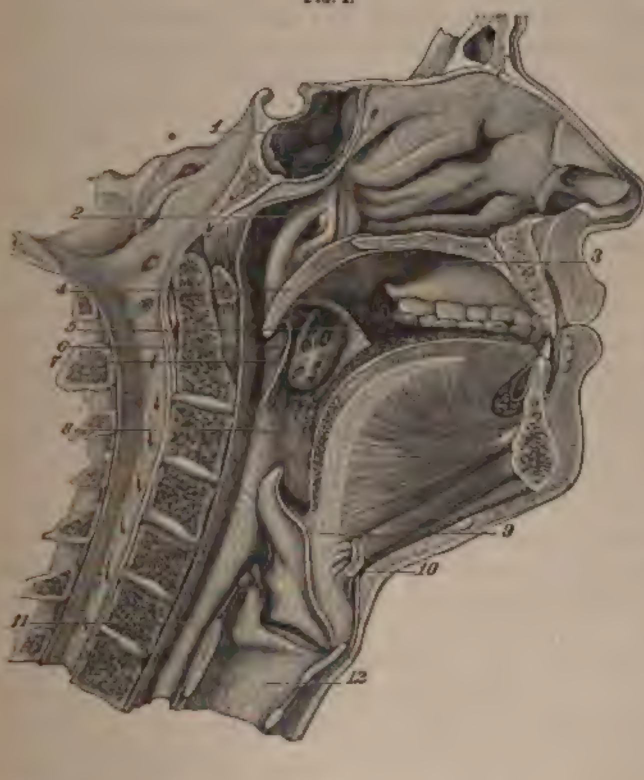
The pharynx, in which the most vigorous and complex of the movements of deglutition take place, is an irregularly funnel-shaped cavity, its longest diameter being transverse and opposite the cornua of the hyoid bone, with its smallest portion at the opening into the œsophagus. Its length is about four and a half inches. It is connected superiorly and posteriorly with the basilar process of the occipital bone and the upper cervical vertebræ. It is imperfectly separated from the cavity of the mouth by the velum pendulum palati, a movable musculo-membranous fold, continuous with the roof of the mouth and marked by a line in the centre, which indicates its original development in two lateral halves. This, which is called the soft palate, when relaxed, presents a concave surface looking toward the mouth, a free, arched border, and a conical process hanging from the centre, called the uvula. On either side of the soft palate are two curved pillars or arches.

The anterior pillars of the fauces are formed by the palato-glossus muscle on either side, and run obliquely downward and forward; the mucous membrane which covers them becoming continuous with the membrane of the base of the tongue. The posterior pillars are more closely approximated to each other than the anterior. They run obliquely downward and backward, their mucous membrane becoming continuous with the membrane covering the sides of the pharynx. Between the lower portion of the anterior and

posterior pillars, are the tonsils; and in the substance of, and beneath the mucous membrane of the palate and pharynx, are small glands, which have already been described.

In Fig. 1 are shown the cavities of the mouth and pharynx, with their relations to the nares and the larynx.

FIG. 1.



Section in the median line of the face and the superior portion of the neck, designed to show the mouth in its relations to the nasal fossæ, the pharynx, and the larynx.—1. Sphenoidal sinuses.—2. Internal orifice of the Eustachian tube.—3. Palatine arch.—4. Velum pendulum palati.—5. Anterior pillar of the soft palate.—6. Posterior pillar of the soft palate.—7. Tonsil.—8. Lingual portion of the cavity of the pharynx.—9. Epiglottis.—10. Section of the hyoid bone.—11. Laryngeal portion of the cavity of the pharynx.—12. Cavity of the larynx. (SAPPEY, *Traité d'anatomie descriptive*, Paris, 1857, tome iii., p. 44.)

The isthmus of the fauces, or the strait through which the food passes from the mouth to the pharynx, is thus bounded above by the soft palate and the uvula; laterally, by the pillars of the palate and the tonsils; and below, by the base of the tongue.

The openings into the pharynx above are the posterior nares and orifices of the Eustachian tubes. Below, are the openings of the œsophagus and the larynx.

The muscles of the pharynx are the superior constrictor, the stylo-pharyngeus, the middle constrictor, and the inferior constrictor; and it is easy to see, from the situation of these muscles, how, by their successive action from above downward, the food is passed into the œsophagus.

The superior constrictors form the muscular wall of the upper part of the pharynx. Their origin extends from the lower third of the margin of the internal pterygoid plate of the sphenoid bone to the alveolar process of the last molar tooth, the intermediate line of attachment being to tendons and ligaments. The fibres then pass backward and meet in the median raphe, which is attached by apeneurotic fibres to a ridge on the basilar process of the occipital bone, called the pharyngeal spine.

The stylo-pharyngeus muscle has a rounded portion above by which it arises from the inner surface of the base of the styloid process of the temporal bone. It passes between the superior and middle constrictors of the pharynx, becomes thin, and spreading out, its fibres mingle in part with the fibres of the constrictors and the palato-pharyngeus, and a few pass to be inserted into the upper border of the thyroid cartilage.

The middle constrictor is a flattened muscle arising from the cornua of the hyoid bone and the stylo-hyoid ligament; its fibres passing backward, spreading into a fan shape, and meeting in the median raphe.

The inferior constrictor is the most powerful of the muscles of the pharynx. It arises by thick fleshy masses from

the sides of the thyroid and cricoid cartilages of the larynx. The inferior fibres curve backward, and the superior fibres backward and upward, to meet in the median raphe.

The muscles which form the fleshy portions of the soft palate are likewise important in deglutition.

The levator palati, a long muscle of considerable thickness, arises from the apex of the petrous portion of the temporal bone and the adjacent cartilaginous portion of the Eustachian tube; and spreading out in the posterior portion of the soft palate, as its name implies, it raises the velum.

The tensor palati, sometimes called the circumflexus, is a broad thin muscle consisting of a vertical portion which is fleshy, and a horizontal portion which is tendinous. The fleshy fibres arise from the scaphoid fossa of the sphenoid bone, pass downward, become tendinous, and wind around the hamular process; after which the muscle spreads out into a thin apeneurosis which passes to the median line on the anterior portion of the soft palate. Its action is to make the palate tense.

The palato-glossus forms the anterior pillar of the soft palate. It arises from the side of the palate near the uvula and passes to be inserted into the side and dorsum of the tongue. The action of this muscle is to constrict the isthmus of the fauces by drawing down the soft palate and elevating the base of the tongue.

The palato-pharyngeus forms the posterior pillar of the soft palate. It arises from the soft palate by two fasciculi, and joins with the fibres of the stylo-pharyngeus, to be inserted into the posterior border of the thyroid cartilage. Its action is to approximate the posterior pillars of the palate and depress the velum.

The azygos uvulæ is the small muscle, consisting of two fasciculi, one on either side, which forms the fleshy portion of the uvula. It has no very marked or important action in deglutition.

The mucous membrane of the pharynx,—aside from the

various glands situated beneath it and in its substance, which have already been described,—presents some peculiarities, which are interesting more from an anatomical than a physiological point of view. In the superior portion, which forms a cuboidal cavity just behind the posterior nares, the membrane is darker and much richer in blood-vessels than in other parts. Its surface is smooth and provided with ciliated columnar epithelium, like that which covers the membrane of the posterior nares. It is marked by a deep antero-posterior groove in the median line; and on either side, parallel with the median line, are four smaller grooves. In the horizontal portions, the mucous membrane in the central groove adheres to the periosteum of the basilar process, particularly at its posterior extremity. Laterally, below the level of the opening of the Eustachian tubes, and posteriorly, at the point where it becomes vertical, the mucous membrane abruptly changes its character. The epithelial covering is here composed of cells of the pavement variety, similar to those which cover the mucous membrane of the œsophagus. The membrane is also paler, and is less rich in blood-vessels. It is provided with papillæ, some of which are simple conical elevations, while others are split into from two to six conical processes with a single base. These papillæ are rather thinly distributed over the whole of that portion of the mucous surface which is covered with pavement-epithelium.

The contractions of the muscular walls of the pharynx force the alimentary bolus into the œsophagus, a tube possessed of thick muscular walls, extending to the stomach. The œsophagus is about nine inches in length. It is cylindrical, and rather constricted at its superior and inferior extremities. It commences in the median line behind the lower border of the cricoid cartilage and opposite the fifth cervical vertebra. At first, as it descends, it passes a little to the left of the cervical vertebræ. It then passes from left to right from the fourth or fifth to the ninth dorsal vertebra, to give place to the aorta. It finally passes a little to the

left again, and from behind forward, to its opening into the stomach. In its passage through the diaphragm, it is surrounded by muscular fibres, so that when this muscle is contracted in inspiration, its action has a tendency to close the opening.

The coats of the œsophagus are two in number, unless we include, as a third coat, the fibrous tissue which attaches the mucous membrane to the subjacent muscular tissue.

The external coat is composed of an external longitudinal, and an internal circular or transverse layer of muscular fibres. In the superior portion, the longitudinal fibres are arranged in three distinct fasciculi: one in front, which passes downward from the posterior surface of the cricoid cartilage; and one on either side, extending from the inferior constrictors of the pharynx. As the fibres descend, the fasciculi become less distinct, and are finally blended into a uniform layer. The circular layer is somewhat thinner than the external layer. Its fibres are transverse near the superior and inferior extremities of the tube, and are somewhat oblique in the intermediate portion. The muscular coat is from $\frac{1}{50}$ to $\frac{1}{12}$ of an inch in thickness.

In the upper third of the tube. the muscular fibres are exclusively of the red or striated variety, with some anastomosing bundles; but lower down, there is a mixture of non-striated fibres, which appear first in the circular layer. These latter fibres become gradually more numerous, until, in the lower fourth, they largely predominate. A few striated fibres, however, are found as low down as the diaphragm.[1]

[1] Kölliker, *Manual of Human Microscopic Anatomy*, London, 1864, p. 314.

Sappey (*Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 92) makes the extraordinary statement that "the fleshy layer of the œsophagus is formed exclusively of smooth fibres." He says that it is very easy to distinguish the striæ of the red fibres with a magnifying power of two-hundred diameters; and that these are never observed in fibres taken from *any part of the œsophagus*. It is remarkable that, at the present day, there should be any difference of opinion concerning a question so easily decided as that of the constitution of the muscular coat of the œsophagus. Immediately before writing this paragraph, we had

The mucous membrane of the œsophagus is attached to the muscular tissue by a dense fibrous layer. It is quite vascular and reddish above, but becomes gradually paler in the inferior portion. The mucous membrane is ordinarily thrown into longitudinal folds, which are obliterated when the tube is distended. Its epithelium is thick, of the pavement variety, and is continuous with, and similar to the covering of the lower portion of the pharynx. It is provided with papillæ of the same structure as those found in the pharynx, the conical variety predominating. Numerous small racemose glands are found throughout the tube, forming by their aggregation at the lower extremity, just before it opens into the stomach, a glandular ring.

Mechanism of Deglutition.—For convenience of description, physiologists have generally divided the process of deglutition into three periods. The first period is occupied by the passage of the alimentary bolus backward to the isthmus of the fauces. This may appropriately be considered as a distinct period, because the movements are effected by the action of muscles entirely under the control of the will. The second period is occupied by the passage of the food from the isthmus of the fauces, through the palate, into the upper part of the œsophagus. The third period is occupied by the passage of the food through the œsophagus into the stomach.

In the first period, the tongue is the important agent.

ocular proof of the inaccuracy of the assertion made by Sappey. In the human œsophagus, there is a manifest difference in color between the upper and lower portions. Above, the color is red; and below, it becomes paler and more like the involuntary muscular tissue. A specimen taken from any of the deep-red portions shows the striæ of the red muscular fibres with a ¼ inch objective as distinctly as could be desired. Passing down the tube, small bands of this red tissue are seen, which likewise present, on microscopic examination, the striated muscular fibre. These we demonstrated down as far as the diaphragm; though in the lower portions, the unstriped fibres were found to predominate. The examinations were made with a binocular microscope, which singularly increases the beauty and distinctness of the appearances.

After mastication has been completed, the mouth is closed and the tongue, collecting with the point aided by the cheeks all the particles of food into a single mass, becomes slightly increased in width, and with the alimentary bolus behind it, is pressed from before backward against the roof of the mouth. The act of swallowing is always performed with difficulty when the mouth is not completely closed; for the tongue, from its attachments, must follow, to a certain extent, the movements of the lower jaw. The first part of the first period of deglutition is thus simple; but when the food has passed beyond the hard palate, it comes in contact with the hanging velum, and the muscles are brought into action which render this membrane tense, and oppose it in a certain degree to the backward movement of the base of the tongue. This is effected by the action of the tensor-palati and the palato-glossus. The moderate tension of the soft palate admits of its being applied to the smaller morsels, while the opening is dilated somewhat forcibly by masses of greater size.

It is easy to appreciate, in analyzing the first period of deglutition, that liquids and the softer articles of food are assisted in their passage to the isthmus of the fauces by a slight suction force. This is effected by the action of the muscles of the tongue, elevating the sides and depressing the centre of the dorsum, while the soft palate is accurately applied to the base.

The importance of the movements of the tongue during the first period of deglutition is evidenced by experiments on the inferior animals, and by cases of loss of this organ in the human subject. In the experiments of Panizza, which have already been referred to in connection with mastication, it was found that paralysis of the tongue, by section of the hypoglossal nerves in dogs, deprived the animals of the power of swallowing, even when a bolus of meat or bread was put upon its anterior surface.[1] We have now a young dog under

[1] PANIZZA, *Nouvelles Recherches Expérimentales sur les Nerfs.—Gazette Médicale de Paris*, 1835, p. 419.

observation, in which both hypoglossal nerves have been divided, and the effect upon deglutition is very marked. The animal eats with difficulty, the pieces of meat which are given him frequently dropping from the mouth. He is only able to swallow by jerking the head suddenly upward, so as to throw the meat past the base of the tongue; and even when deglutition commences, the first steps take place slowly and with apparent difficulty. The process of drinking is very curious. The animal makes the usual noise in attempting to drink, but the tongue does not come out of the mouth, and the only way he seems to get any water is by jerking the head and moving the jaw so as to throw some of the liquid into the mouth. When he attempts to drink from a basin, the water is spattered in every direction. He appears to get more from a tall, narrow vessel. On causing him to drink from a graduated glass, it was found that he drank four fluid ounces in four minutes. In the case of a young girl, reported to the Academy of Science, in 1718, by De Jussieu, in which there was congenital absence of the tongue, deglutition was impossible until the food had been pushed with the finger far back into the mouth.[1] In cases of amputation of the tongue, a sufficient portion of its base generally remains to press against the palate and effect deglutition.

The movements in the first period of deglutition are under the control of the will, but are generally involuntary. When the food has been sufficiently masticated, it requires an effort to prevent the act of swallowing. In this respect the movements are like the acts of respiration; except that the imperative necessity of air in the system must, in a short time, overcome any voluntary effort by which respiration is arrested.

[1] De Jussieu, *Observation sur la manière dont une Fille sans Langue s'acquit des fonctions qui dépendent de cet organe.—Mémoires de l'Académie Royale des Sciences*, Paris, 1718, p. 8.

The second period of deglutition involves more complex and important muscular action than the first. By a rapid and almost convulsive series of movements, the food is made to pass through the pharynx into the œsophagus. The movements are now entirely beyond the control of the will, and belong to the kind usually called reflex. After the alimentary mass has passed beyond the isthmus of the fauces, it is easy to observe a sudden and peculiar movement of elevation of the larynx by the action of muscles which usually depress the lower jaw, but which are now acting from this bone as the fixed point. The muscles which produce this movement act chiefly upon the hyoid bone. They are the digastric (particularly the anterior belly), the mylo-hyoid, the genio-hyoid, the stylo-hyoid, and some of the fibres of the genio-glossus. It is probable, also, that the thyro-hyoid acts at this time to draw the larynx toward the hyoid bone. With this elevation of the larynx, there is necessarily an elevation of the anterior and inferior portions of the pharynx, which are, as it were, slipped under the alimentary bolus as it is held by the constrictors of the isthmus of the fauces.

Contraction of the constrictor muscles of the pharynx takes place almost simultaneously with the movement of elevation; and the superior constrictor is so situated as to grasp the morsel of food, and with it the soft palate. The mechanism of this act was first fully described by Gerdy.[1]

According to this description, the pharynx closely and suddenly embraces the velum with the base of the tongue, entirely obliterates the lower part of its cavity, and forces the alimentary bolus to pass out. It is easy to understand, then, how readily the food, made into a yielding mass by mastication and insalivation, and coated with slimy mucus, can be made to pass through the isthmus of the fauces over the membrane, which is covered also with a glairy secretion. The middle and inferior constrictors—the largest and most

[1] Gerdy, *Note sur les mouvements de la langue et quelques mouvements du Pharynx.—Bulletin des Sciences Médicales*, Paris, 1830, tome xx., p. 33.

powerful of the muscles of the pharynx—and the stylo-pharyngeus contract in connection with the superior constrictors. These muscles, the constrictors acting from the median raphe, assist to elevate the anterior and inferior walls of the pharynx and pass the food rapidly into the upper part of the œsophagus. All these complex movements are accomplished with great rapidity, and the larynx and pharynx are then immediately returned to their original position.

Protection of the Posterior Nares during the Second Period of Deglutition.—When the act of deglutition is performed with regularity, no portion of the liquids and solids swallowed ever find their way into the air-passages. The entrance of foreign substances into the posterior nares is prevented in part by the action of the superior constrictors of the pharynx, which, as we have seen, embrace, during their contraction, not only the alimentary mass, but the velum pendulum palati itself; and in part, also, by contraction of the muscles which form the posterior pillars of the soft palate.

During the first part of the second period of deglutition, the soft palate is slightly raised, being pressed upward by the morsel of food. This fact has been observed in cases in which the parts have been exposed by surgical operations,[1] and was demonstrated by M. Debrou, who passed a tube along the floor of the nares to the pharynx, and noted a sudden depression of the end projecting from the nose with each act of swallowing, as though the soft palate struck suddenly against the other extremity.[2] This mechanism has also been observed in the human subject by Bidder and Kobelt. In this case—a young man who had lost the superior maxillary bone, as well as the zygoma—the soft palate could be observed from its superior surface; and at each movement of

[1] Bérard (*op. cit.*, tome ii., p. 25) cites a case of this kind observed by Ridder.

[2] Debrou, *Thèses de l'École de Médecine de Paris*, 1841, No. 266, p. 8.

deglutition, the palate, naturally inclined downward, became more horizontal, and the posterior wall of the pharynx came forward to meet it. The same movement of the pharynx was observed by Kobelt in the case of a soldier who received a severe sabre-cut in the neck.[1]

While the food is passing the pharynx, the palato-pharyngeal muscles, which form the posterior pillars of the soft palate, are in a state of contraction by which the edges of the pillars are nearly approximated, forming, with the uvula between them, almost a complete diaphragm between the postero-superior and the antero-inferior parts of the pharynx. This, with the application of the posterior wall of the pharynx to the superior face of the soft palate, completes the protection of the posterior openings of the nasal fossæ. The fact that the posterior pillars are thus contracted and approximated during deglutition may be easily verified by simply watching these parts with a mirror during an effort at swallowing. In the following case, observed by Bérard, it was shown that the muscular action of the soft palate was absolutely necessary to the protection of the nares, particularly in swallowing liquids: A young lady was affected with complete paralysis of the velum, which allowed liquids to return so freely by the nose in swallowing that she was obliged to retire from observation whenever she drank.[2]

[1] BÉCLARD, *Traité Elémentaire de Physiologie Humaine*, Paris, 1859, p. 60.

[2] *Op. cit.*, p. 24.

In a late article by M. Moura on the mechanism of deglutition, published in the *Journal de l'Anatomie et de la Physiologie*, there are some interesting observations upon the function of the velum of the palate in man and in the inferior animals. While M. Moura fully recognizes the mechanism by which the velum closes the posterior nares, in man, and shows that any interference with its functions seriously disturbs the act of deglutition, he has found that the velum of the palate could be entirely removed in the dog without any such result; the animal accomplishing the deglutition of both solids and liquids without difficulty and without any return of these matters by the nares. This he explains by certain important anatomical differences between the organs of deglutition in man and in the dog. (MOURA, *Mémoire sur l'Acte de la Déglutition.—Journal de l'Anatomie et de la Physiologie*, Paris, 1867, tome iv., p. 168.

Protection of the Opening of the Larynx, and Uses of the Epiglottis in Deglutition.—The entrance of the smallest quantity of solid or liquid foreign matter into the larynx produces violent and distressing cough. This accident is of not infrequent occurrence, especially when an act of inspiration is inadvertently performed while solids or liquids are in the pharynx. During inspiration, the glottis is widely opened, and at that time only can a substance of any considerable size find its way into the respiratory passages. Respiration is interrupted, however, during each and every act of deglutition; and there can, therefore, be hardly any tendency at that time to the entrance of foreign substances into the larynx. During a regular act of swallowing, nothing can find its way into the respiratory passages, so complete is the protection of the larynx during the period when the food passes through the pharynx into the œsophagus.

The situation of the epiglottis has naturally led physiologists to attribute to it great importance in preventing the entrance of particles of food and liquids into the larynx. It will be remembered that this cartilaginous leaf-like process is attached to the anterior portion of the larynx, and is usually erect, lying against the base of the tongue. In the movements of the tongue and larynx incident to deglutition, the epiglottis is necessarily applied to the superior face of the larynx so as to close the opening. Although, during deglutition, the glottis is covered in this way, it is necessary to study closely all the conditions which are involved, and ascertain what is the actual value of each of the various means by which entrance of foreign bodies into the air-passages is prevented; for this protection is accomplished by several distinct provisions.

It is evident from the anatomy of the parts and the necessary results of the contractions of the muscles of deglutition, that while the food is passing through the pharynx, the larynx, by its elevation, passes under the tongue as it moves backward, and the soft base of this organ is, as it

were, moulded over the glottis. With the parts removed from the human subject or from one of the inferior animals, we can imitate the natural movements of the tongue and larynx, and it is evident that this provision alone must be sufficient to protect the larynx from the entrance of solid or semi-solid particles of food; particularly when we remember how the alimentary particles are agglutinated by the saliva, and how easy their passage becomes over the membrane coated with a slimy mucus. Experiments on the inferior animals and observations upon the human subject have conclusively settled the question that the deglutition of all articles, except liquids, is generally effected without difficulty, when the epiglottis has been removed or lost by accident or disease. The same is true when, in addition, the intrinsic muscles of the larynx have been paralyzed by the section of nerves, or even when closure of the rima glottidis is forcibly prevented. It has been shown, however, by the experiments of Longet, that when the larynx is in part prevented from performing its movement of ascension, the deglutition of a moist mass of alimentary matter is effected with difficulty and is followed by a sharp cough; indicating the entrance of a certain quantity of foreign matter into the air-passages.[1]

It is impossible for the muscles of the pharynx to contract without drawing together the sides of the larynx, to which they are attached, and assisting to close the glottis. At the same time, as the movements of respiration are arrested during deglutition, the lips of the glottis fall together; as they always do except in inspiration. This fact we have repeatedly observed in demonstrating the respiratory movements of the glottis; for when the larynx is thus exposed, the animal makes frequent efforts at deglutition. In addition to this passive and incomplete approximation of the vocal cords, it has repeatedly been observed that the lips of the glottis are accurately and firmly closed during each act of deglutition. This fact was first actually

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 112.

observed by Magendie in dogs, in his experiments on the uses of the epiglottis in deglutition.[1] Magendie believed that this act was sufficient to protect the air-passages from the entrance of all substances, liquid as well as solid. The experiment of Longet, cited above, shows that this is not the case; for if the movements of ascension of the larynx be interfered with, liquids and moist articles are liable to find their way into its cavity. The conclusions arrived at by Magendie concerning the importance of the epiglottis in deglutition have not been absolutely verified by the experiments of others, nor are they carried out by observations on the human subject; for when this part is entirely absent, liquids are liable to penetrate the larynx.

The experiments of Longet with regard to the importance of the closure of the glottis itself in deglutition are very interesting.[2] This observer divided, first of all, the recurrent laryngeal nerves and the branch of the superior laryngeal going to the crico-thyroid muscle, thus paralyzing all of the muscles of the larynx. Notwithstanding this, he found the occlusion of the glottis complete with every act of deglutition, and demonstrated that this was due to the powerful contraction of the inferior constrictors of the pharynx, drawing together the sides of the larynx. In two sheep and two dogs, after having removed a portion of the trachea, he kept the glottis open by the introduction from below of a dissecting forceps, and found that notwithstanding the impossibility of closing the glottis, neither solids nor liquids penetrated the trachea in swallowing. These experiments show conclusively that although the glottis is accurately closed during deglutition, this is not absolutely

[1] MAGENDIE, *Mémoire sur l'usage de l'Epiglotte dans la Déglutition*, Paris, 1813, p. 3.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 108, and *Recherches Expérimentales sur les Fonctions de l'Epiglotte et sur les Agents de l'occlusion de la Glotte dans la Déglutition, le Vomissement et la Rumination.—Archives Générales de Médecine*, Paris, 1841, 3me Série, tome xii., p. 417 *et seq.*

necessary to the protection of the air-passages from the entrance of solids or liquids.

Longet justly attaches great importance to the exquisite sensibility of the top of the larynx in preventing the entrance of foreign substances. His experiments of dividing all the nervous filaments distributed to the intrinsic muscles show that their action is not essential. But on division of the superior laryngeal, the nerve which gives sensibility to the parts, he found that liquids occasionally passed in small quantity into the trachea. This is attributed to the want of sensibility in the mucous membrane above the glottis: "for the animal is not aware in time of the presence of liquid which may accidentally get into the supra-laryngeal cavity, the occlusion of the glottis is sometimes too tardy and does not take place until after the passage of the liquid; or, again, the animal, instead of then making a sudden expiration, makes an unseasonable inspiration which facilitates the introduction of the foreign substance into the air-passages, and the cough does not take place until this is already in contact with the tracheal or bronchial mucous membrane."[1]

These experiments beautifully illustrate the conservative

[1] *Op. cit.*, tome i., p. 110. The two most elaborate and interesting articles on the occlusion of the glottis in deglutition are those of Magendie and Longet. The memoir of Magendie was presented to the first class of the Institute of France in March, 1813. It contains the first experiments on record concerning the uses of the epiglottis in deglutition, and the effects of its removal in the inferior animals. The very elaborate memoir of Longet was published in the *Archives Générales*, in 1841. Magendie showed that section of the inferior laryngeal nerves, paralyzing all the muscles of the larynx except the arytenoid and crico-thyroid, did not interfere with deglutition, even in the case of liquids; while after section of the superior laryngeals, the deglutition of liquids was frequently followed by convulsive cough. From this he concluded that the muscles animated by the superior laryngeal nerves were chiefly concerned in protecting the glottis. The later and more minute experiments of Longet, however, proved this conclusion to be an error. He showed that the cough occurred after the deglutition of liquids, when the sensitive filaments of the superior laryngeals had been divided leaving the muscular branches intact; and he demonstrated that the difficulty lay in the loss of sensibility of the mucous membrane, and not in paralysis of the crico-thyroid muscles.

function of the acute sensibility of the mucous membrane above the glottis. No foreign substance can find its way into the air-passages by simply dropping into the cavity situated above the vocal cords when respiration is interrupted, but can only enter by being drawn in forcibly and suddenly with an act of inspiration, when the glottis is widely opened. It is now well known to the practical physician that direct applications cannot be made to the interior of the larynx, unless an instrument be suddenly introduced with the inspiratory act; and at this time, a little dexterity will enable an operator to introduce bodies of considerable size below the vocal cords.

Functions of the Epiglottis.—Before the experiments of Magendie, in 1813, physiologists were generally of the opinion, judging from anatomical relations, that the epiglottis had the function of protecting the larynx from the entrance of particles of food during the second period of deglutition. There were, however, some who did not entirely adopt this view. Pinel and Percy, the reporters of a commission from the Institute to examine the memoir of Magendie, mention the fact that Guglielmini and Targioni had already noted, in cases of persons in whom the epiglottis was entirely absent, that no inconvenience was experienced during deglutition.[1] Magendie extirpated the entire epiglottis in dogs, and found that the animals swallowed liquids and solids without difficulty, the act being very seldom followed by cough. The observations on deglutition were made an hour after the removal of the epiglottis. In other animals the superior and inferior laryngeal nerves were divided, thus paralyzing the muscles of the glottis; when the deglutition of liquids especially became difficult, and was followed generally by cough. As the result of these observations, Magendie came to the

[1] *Rapport de la Classe des Sciences physiques et mathématiques de l'Institut Impérial de France, sur le Mémoire de M. Magendie, concernant l'usage de l'Épiglotte dans la Déglutition.*—Report attached to the memoir, p. 21.

conclusion, as we have already noted, that the larynx is protected during deglutition by closure of the glottis itself.

Although these experiments on animals were apparently conclusive, the reporters of the Institute quoted observations of Mercklin and Bonnet on the human subject, in which, after the destruction of the epiglottis by disease, there existed persistent difficulty in swallowing liquids. In these cases, however, the reporters attribute the difficulty rather to "pathological alterations of the true organs of deglutition than to destruction of the epiglottis, which could not be affected without involving changes unfavorable to their action."[1] As numerous pathological observations of this character have been reported, the question could not be regarded as entirely settled by the researches of Magendie. It was with the view of determining this more rigorously, that further experiments were instituted in 1841 by Longet.[2]

In investigating this question, Longet removed the epiglottis from six dogs. He found that in the animals kept until the parts were perfectly cicatrized, more or less cough followed the deglutition of liquids. One of these he kept for six months, and found that when he drank milk or water cough never failed to follow. The same fact was noted in three of the animals that were killed on the nineteenth day, and in one that was killed on the thirtieth day. In all, the complete excision of the epiglottis was verified by post-mortem examination. In one of the animals, killed two days after the operation, that generally swallowed liquids without coughing, there was found a swelling at the base of the tongue which projected over the larynx.[3]

It is evident from these experiments that the observations of Magendie were not sufficiently extended, as he does not

[1] Ibid.

[2] *Op. cit.*

[3] LONGET, *Recherches Expérimentales sur les Fonctions de l'Épiglotte et sur les Agents d'occlusion de la Glotte dans la Déglutition, le Vomissement et la Rumination.—Archives Générales*, Paris, 1841, 3me Série, tome xii., p. 418 *et seq.*, and *Traité de Physiologie*, Paris, 1861, tome i., p. 105.

report that they were continued after sufficient time had elapsed for the parts to cicatrize. At all events, it is necessary, in this instance, to confirm the results of experiments on animals by observations on the human subject.

Several cases of loss of the epiglottis in the human subject are quoted by Longet in support of his view that this part is necessary to the complete protection of the air-passages, particularly in the deglutition of liquids. Two of the most striking of these cases were observed by Larrey in Egypt. One of these was the case of General Murat, who was wounded by a ball passing through the neck from one angle of the jaw to the other, cutting off the epiglottis, which was expelled by the mouth. In this instance, the difficulty in the deglutition of liquids was so great, that it became necessary to introduce them through a tube passed into the œsophagus. In the other case, the epiglottis was likewise entirely removed by a wound and was preserved and presented to the surgeon. In this instance, the difficulty in the deglutition of liquids was even greater than in the former; each effort at swallowing being followed by convulsive and suffocating cough. This difficulty persisted after the parts had become completely cicatrized. In these cases it is possible that the injury to muscles and other parts from such severe wounds might interfere with the movements of the larynx or the closure of the glottis, and thus disturb deglutition. In a case in which the epiglottis had entirely sloughed away as a consequence of syphilitic disease, which has already been referred to in the previous volume,[1] the difficulty in swallowing liquids, though sufficiently well marked, was by no means as great as in the cases mentioned above. The difficulty in swallowing was noted as not great, but the patient swallowed liquids more easily than solids. The difficulty consisted of cough and loss of breath, as the patient described it. It was less when articles were swallowed while the patient was in the recumbent

[1] See vol. i., p. 359.

posture, and food and drink were habitually taken in that position. At the time that this patient, a female, was in the Bellevue Hospital, under the observation of Dr. Flint, the deglutition was improving. Dr. Flint noted that after she had been in the hospital a few days, on causing her to swallow in his presence, the act of deglutition was performed *with a certain deliberation but without difficulty.* An examination of the parts with the laryngoscope was made by Dr. Church, in the presence of Dr. Flint and Dr. Dalton: "The absence of the epiglottis was determined by sight. The vocal cords were distinctly seen. The little excrescences described as apparent to the touch were visible."[1]

In the case just described, there was not a constant and considerable difficulty in deglutition; but it is stated that difficulty had existed, undoubtedly from the passage of articles into the larynx; and when no such accident took place the act was performed with a "certain deliberation." It is a curious fact, also, that when the difficulty in swallowing was considerable, deglutition was accomplished most easily in the recumbent posture, in which the tendency of particles of food to pass into the larynx must have been much lessened.

While, with attention on the part of the subject, the larynx may frequently, and perhaps generally, be protected from the entrance of foreign substances during deglutition after loss of the epiglottis when other parts are not affected, a study of the numerous cases of this lesion as the result of disease or injury shows that the epiglottis is by no means so inefficient in the protection of the larynx as was supposed by Magendie. Still it is but one of the means which have been provided for this end.

Since the air-passages have been so fully explored by means of the laryngoscope, this instrument has been used to a certain extent in the study of the phenomena of deglutition.

[1] The points in the history of this case bearing on the functions of the epiglottis in deglutition were taken from the hospital records of Dr. Flint, by whom they were personally noted.

In July, 1865, a note was presented to the French Academy of Sciences, giving the results of experiments by Dr. Krishaber on the mechanism of deglutition as studied by autolaryngoscopy, followed by a note on the same subject by M. H. Guinier.[1] Dr. Krishaber, as the result of his observations, gives the following conclusions:

"1st. In the act of deglutition the alimentary bolus passes in one of the pharyngeal grooves, over one of the sides of the epiglottis tilted by the elevation of the larynx; the bolus thus arrives at the œsophagus at the moment when, by the contraction of the constrictor muscles, the pharynx is shortened and brought in front of the mass.

"2d. The deglutition of liquids is effected in the same manner; these passing, however, quite frequently upon the epiglottis itself, which happens very rarely with solid aliments.

"3d. A quantity—extremely small, it is true—of liquid engages itself during normal deglutition around the border of the epiglottis, and moistens the mucous membrane of the larynx and even of the vocal cords.

"4th. In gargling, the larynx being widely opened, a larger quantity finds its way into the vocal organ.

"5th. An alimentary bolus may be easily tolerated in the respiratory passages; that is to say, in the larynx, as far as the vocal cords, and *even in the interior of the trachea.*

"6th. The sensibility of the trachea to the impression of foreign bodies is infinitely less than that of the larynx.

"7th. Hard and cold bodies, as, for example, a sound, are not tolerated in the respiratory passages; while any soft body, which can adhere to the mucous membrane and has a temperature like that of the parts touched, is easily tolerated in the respiratory passages and kept in the trachea many minutes without producing the slightest cough."

These observations confirm the views of Longet and others concerning the passage of alimentary substances

[1] *Gazette Médicale de Paris*, 15 juillet, 1865, p. 435.

down the pharynx by the sides of the epiglottis; and in that case, liquids would almost certainly pass around the borders in quantity sufficient to moisten the mucous membrane below. It must be remembered, however, that the sensibility of the air-passages is very unequal in different persons, and that it may be considerably modified by education of the parts. This should make us hesitate to accept the view that, in gargling, the larynx receives a quantity of liquid, and that an alimentary bolus may be tolerated in the trachea for many minutes without coughing. Though this may be true in the person of Dr. Krishaber, common experience shows that it is not generally the case.[1]

To sum up the mechanism by which the opening of the larynx is protected during the deglutition of solids and liquids, we have only to carefully follow the articles as they pass over the inclined plane formed by the back of the tongue and the anterior and inferior part of the pharynx. As the food is making this passage in obedience to the contraction of the muscles which carry the tongue backward, draw up the larynx, and constrict the pharynx, the soft base of the tongue and the upper part of the larynx are applied to each other, with the epiglottis, which is now inclined backward, between them; at the same time, the glottis is closed, in part by the action of the constrictor muscles attached to the sides of the thyroid cartilages, and in part by the action of its intrinsic muscles. If the food be tolerably consistent and

[1] The note of M. H. Guinier mentions experiments on deglutition observed by autolaryngoscopy in which, by performing the act of swallowing slowly and imperfectly, so as not to close the pharynx, he was able to exhibit the phenomena to a number of persons. He showed that the action of the epiglottis was not absolutely necessary to protect the larynx during the passage of the alimentary bolus from the pharynx to the œsophagus, and that the passages could be protected by simple closure of the vocal cords; and that in gargling, the space above the superior vocal cords was filled and the liquid agitated by the air as it was allowed to pass slowly from the glottis. As regards the function of the epiglottis, it must be remembered that in these experiments, deglutition was not and could not be normal. The observations on gargling, however, seem very satisfactory.

united into a single bolus, it slips easily from the back of the tongue along the membrane covering the anterior and inferior part of the pharynx; but if it be liquid or of little consistence, a portion takes this course, but another portion passes over the epiglottis, being directed by it into the two grooves or gutters by the side of the larynx.

It is by these means, together with those by which the posterior nares are protected, that all solids and liquids are directed to the œsophagus, and the second period of deglutition is safely accomplished.

The third period of deglutition is the most simple of all. It involves merely contractions of the muscular walls of the œsophagus, by which the food is forced into the stomach. The longitudinal fibres shorten the tube and slip the mucous membrane, lubricated by its glairy secretion, above the bolus; while the circular fibres—by a progressive peristaltic contraction from above downward—strip the food, as it were, into the stomach. This shortening of the tube was well illustrated in an observation on a female suffering under a gastric fistula, by Halle; who noted a protrusion of the mucous membrane—which naturally undergoes no shortening—into the stomach with each act of deglutition.[1] The passage of food down the œsophagus was for the first time closely studied by Magendie; who noted, in this connection, many curious and important facts. In numerous experiments on the lower animals, he observed that while the peristaltic contractions of the upper two-thirds of the tube were immediately followed by a relaxation which continued till the next act of deglutition, the lower third remained contracted generally for about thirty seconds after the passage of the food into the stomach. During its contraction, this part of the œsophagus was hard, like a cord firmly stretched. This was followed by relaxation; and this alternate contraction and relaxation continued constantly, even when the stomach

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 69.

was empty; though during digestion, the contractions were frequent in proportion to the quantity of food in the stomach. The contraction was always increased by pressing the stomach and attempting to pass some of its contents into the œsophagus.[1] This provision is undoubtedly important in preventing regurgitation of the contents of the stomach, especially when the organ is exposed to pressure, as in urination or defecation. We have already noted the action of the crura of the diaphragm, which have a tendency to close the œsophageal opening during inspiration.[2]

The length of time occupied in the third period of deglutition was noted by Magendie in the inferior animals, but we have been unable to find any definite observations on this point in the human subject; though this would have been easy in the cases of gastric fistula which, from time to time, have come under the observation of physiologists. Magendie found that the alimentary bolus sometimes occupied two or three minutes in its passage, and that it was often momentarily arrested in its course. It frequently seems as though we were ourselves conscious of a very slow passage of food down the œsophagus, and not infrequently a piece of bread or a mouthful of liquid is taken to hasten it; but it is not probable that every alimentary bolus remains for two or three minutes in the œsophagus, and liquids undoubtedly are swallowed with considerable rapidity, as they can soon be recognized in the stomach by their temperature. As the lower part of the œsophagus is composed chiefly of unstriped muscular fibres, it is probable that here the contractions are more gradual than in the upper portions.

As we have already had occasion to remark, the muscular movements which take place during all the periods of deglutition are peculiar. The first act is generally involuntary from

[1] MAGENDIE, *Mémoire sur l'Œsophage, lu à l'Institut de France*, le 11 octobre, 1813.

[2] See vol. i., Respiration, p. 370.

inattention, but is under the control of the will. The second act is involuntary, when once commenced, but may be excited by the voluntary passage of solids or liquids beyond the velum pendulum palati. It is impossible to perform the second act of deglutition unless there be some article, either solid or liquid, in the pharynx. It is easy to make three or four successful efforts consecutively, in which there is elevation of the larynx with all the other characteristic movements; but a little attention will show that with each act a small quantity of saliva is swallowed. When the efforts have been frequently repeated, the movements become impossible until time enough has elapsed between them for the saliva to collect. This fact was personally verified before writing this paragraph; and it was demonstrated to be due to the absence of liquid; for immediately after, an ounce of water was swallowed without difficulty by sixteen successive movements of deglutition. This experiment also shows the small quantity of liquid (only half a drachm) necessary to excite the contraction of the muscles concerned in the second act.

All the movements of deglutition, except those of the first period, must be regarded as essentially reflex, *i. e.*, depending upon an impression made upon the afferent nerves distributed to the mucous membrane of the pharynx and œsophagus.[1]

The position of the body has little to do with the facility with which deglutition is effected. Liquids or solids may be swallowed indifferently in all postures. Bérard states that a juggler, in his presence, passed an entire bottle of wine from the mouth to the stomach, while standing on his head.[2] The same feat we have lately seen accomplished with apparent ease, by a juggler who drank three glasses of ale, while standing on his hands in the inverted posture.

[1] The study of the connection of deglutition with the nervous system is deferred until we come to treat specially, in another volume, of the functions of the nerves.

[2] BÉRARD, *Cours de Physiologie*, Paris, 1849, tome ii., p. 32.

Deglutition of Air.—In the celebrated essay of Magendie on the mechanism of vomiting, it is stated that as soon as nausea commenced the stomach began to fill with air, so that before vomiting occurred, the organ became tripled in size. Magendie showed, furthermore, that the air entered the stomach by the œsophagus, for the distension occurred when the pylorus was ligated.[1] In a subsequent memoir, the question of the deglutition of air, aside from the small quantity which is incorporated with the food during mastication and insalivation, was further investigated.[2] It was found that some persons had the faculty of swallowing air, and, by practice, Magendie himself was able to acquire it, though it occasioned such distress that it was discontinued. Out of a hundred students of medicine, eight or ten were found able to swallow air.

It is not very uncommon to find persons who have gradually acquired this habit in order to relieve uncomfortable sensations in the stomach; and when confirmed, it occasions persistent disorder in the process of digestion. Quite a number of cases of this kind are reported by Magendie, and in several it was carried to such an extent as to produce great distension of the abdomen. A curious case of habitual air-swallowing is reported by Dr. Flint in his recent work on the Practice of Medicine.[3]

Although the subject of air-swallowing properly belongs to pathology, the fact that the muscles of deglutition are capable, in some individuals, of forcing air into the stomach, is not without physiological interest.

[1] Magendie, *Mémoire sur le Vomissement*, Paris, 1813, p. 13 *et seq.* In the memoir on the œsophagus, an experiment is described in which a ligature was applied to this canal near the diaphragm, and it was found that "the air, which during the nausea tries to pass into the stomach, is arrested by the ligature and distends the œsophagus."—(*Op. cit.*, p. 10.)

[2] Magendie, *Mémoire sur la Déglutition de l'Air Atmosphérique, lu à l'Institut, le 25 octobre*, 1813.

[3] Flint, *A Treatise on the Principles and Practice of Medicine*, Philadelphia, 1866, p. 367.

CHAPTER VIII.

STOMACH-DIGESTION—GASTRIC JUICE.

Physiological anatomy of the stomach—Peritoneal coat—Muscular coat—Mucous coat—Glandular apparatus in the stomach—Gastric tubules—Mucous follicles—Closed follicles—Gastric juice—Mode of obtaining the gastric juice—Gastric fistula in the human subject—Secretion of the gastric juice—Secretion in different parts of the stomach—Quantity of gastric juice—Composition of the gastric juice—Organic principles of the gastric juice—Source of the acidity of the gastric juice—Ordinary saline constituents of the gastric juice.

Physiological Anatomy of the Stomach.

THE most dilated portion of the alimentary canal, in man, is the stomach. It serves the double purpose of a receptacle for the food and an organ in which certain important digestive processes take place. It is situated in the upper part of the abdominal cavity, and is held in place by folds of the peritoneum and by the œsophagus. Its form is not easily described. It has been compared to a bagpipe, which it resembles somewhat, when moderately distended. As we should naturally suppose, from the fact that the stomach periodically receives considerable quantities of solids and liquids, its form and position are subject to great variations. When empty, it is flattened, and in many parts its opposite walls are in contact. When moderately distended, its length is from thirteen to fifteen inches, its widest diameter about five inches, and its capacity one hundred and seventy-five cubic inches, or about five pints.[1] The parts usually noted

[1] BRINTON, *Cyclopædia of Anatomy and Physiology*, London, 1859, Supplement, p. 308.

in anatomical descriptions are: a greater and a lesser curvature; a greater and a lesser pouch; a cardiac, or œsophageal opening; and a pyloric opening, which leads to the intestinal canal. The great pouch is sometimes called the fundus.

The coats of the stomach are three in number: the peritoneal, muscular, and mucous. By some, the fibrous tissue which unites the mucous to the muscular coat is regarded as a distinct covering, and is called the fibrous coat.

Peritoneal Coat.—This is simply a process of the peritoneum, similar in structure to the membrane which covers the other abdominal viscera. It is a reflection of the membrane which lines the general abdominal cavity, which, on the viscera, is somewhat thinner than it is on the walls of the cavity. Over the stomach, the peritoneum is from $\frac{1}{300}$ to $\frac{1}{500}$ of an inch in thickness. It belongs to the class of serous membranes, and consists of fibres of the white inelastic tissue, mingled with a considerable number of elastic fibres. It is closely adherent to the subjacent muscular coat, and is not very abundantly supplied with blood-vessels and nerves. Lymphatics have only been demonstrated in the subserous structure. The surface of the peritoneum is everywhere covered with regularly polygonal flattened cells of pavement or tessellated epithelium, closely adherent to each other, and presenting a perfectly smooth surface which is continually moistened with a small quantity of watery secretion. An important function of this membrane is to present a smooth surface covering the abdominal parietes and viscera, so as to allow of free movements of the viscera over each other and against the walls of the abdomen. In the case of the hollow viscera especially, this membrane, from its structure, must give them considerable strength.

Muscular Coat.—Throughout the whole of the alimentary canal, from the cardiac opening of the stomach to the anus,

the muscular fibres forming the middle coat are of the involuntary, pale, or unstriped variety. These fibres, called sometimes muscular fibre-cells, are very pale, with faint outlines, fusiform or spindle-shaped, and presenting an oval longitudinal nucleus. They are very closely adherent by their sides; and are so arranged as to dove-tail into each other, and form sheets of greater or less thickness, depending upon the number of their layers. The muscular coat of the stomach varies in thickness in different animals. In the human subject, it is thickest in the region of the pylorus and is thinnest at the fundus. Its average thickness is about $\frac{1}{24}$ of an inch. In the pylorus, it is from $\frac{1}{16}$ to $\frac{1}{12}$ of an inch thick, and in the fundus from $\frac{1}{48}$ to $\frac{1}{36}$ of an inch.[1]

The muscular fibres exist in the stomach in two principal layers; an external longitudinal layer and an internal circular layer, with a third layer of oblique fibres extending only over the great pouch, which is internal to the circular layer. The direction of the fibres in these layers can generally be seen in a stomach which has been dried and inflated. The longitudinal fibres are continued from the œsophagus, and are most marked in the lesser curvature. They are not continued very distinctly over the rest of the stomach. The circular and oblique fibres are best seen when the organ has been everted and the mucous membrane carefully removed. The circular layer is not very distinct to the left of the cardiac opening, over the great pouch; but in other parts is tolerably regular. Toward the pylorus, the fibres become more numerous, and at the opening into the duodenum, form a powerful muscular ring, which is sometimes called the sphincter of the pylorus, or the pyloric muscle. At this point they project considerably into the calibre of the organ and cease abruptly at the opening into the duodenum, so as to form a sort of valve, presenting, when contracted, a flat surface looking toward the intestine. The oblique layer takes the place, in great part, of the circular fibres over the great

[1] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 316.

pouch. It extends obliquely over the fundus from left to right, and ceases by rather a distinct line extending from the left margin of the œsophagus to about the junction of the middle and last third of the great curvature. This anatomical fact is interesting, for it is at about the point where the oblique layer of fibres ceases that the stomach becomes constricted during the movements which are incident to digestion, dividing the organ into two tolerably distinct compartments.

The blood-vessels of the muscular coat are quite numerous, and are arranged in a peculiar rectangular network, which they always present in the non-striated muscular tissue. The nerves belong chiefly to the sympathetic system, and are demonstrated with difficulty.

Mucous Coat.—As we pass from the œsophagus to the stomach, a very marked change takes place in the character of the mucous membrane. The white, hard appearance of the œsophageal lining, due to its covering of pavement epithelium, abruptly ceases, presenting a sharply defined, dentated border; and the membrane of the stomach is soft, velvety in appearance, and of a reddish-gray color. In some of the inferior animals, as the horse, the characteristic membrane of the œsophagus is prolonged into the stomach and forms a large white zone around the cardiac opening, with abruptly defined edges, contrasting strongly with the rest of the lining membrane of the stomach.

The mucous lining of the stomach is loosely attached to the submucous muscular tissue, and is thrown into large longitudinal folds, which become effaced as the organ is distended. When the muscular coat of the stomach is in a condition of cadaveric rigidity, the longitudinal folding of the mucous membrane is very marked. If the mucous membrane be stretched, or if the stomach be everted and distended, and the mucus, which always exists in greater or less abundance over the surface, be gently removed under a

stream of water, the membrane will be found marked with innumerable polygonal pits or depressions, enclosed by ridges, which in some parts of the organ are quite regular. These are best seen with the aid of a simple lens, as many of them are quite small. The size of the pits is very variable, but the average is about $\frac{1}{200}$ of an inch. This appearance is not distinct toward the pylorus; the membrane here presenting irregular conical projections, and some well-marked villi resembling those found in the small intestine. The surface of the mucous membrane is covered with columnar or prismoidal epithelium; the cells being tolerably regular in shape, with a clear nucleus and a distinct nucleolus.

The thickness of the mucous membrane of the stomach varies in different parts. It is usually thinnest near the œsophagus, and thickest near the pylorus. Its thinnest portion measures from $\frac{1}{72}$ to $\frac{1}{48}$ of an inch; its thickest portion from $\frac{1}{16}$ to $\frac{1}{12}$ of an inch; and the intermediate portion about $\frac{1}{24}$ of an inch.

Glandular Apparatus of the Stomach.—Extending from the bottoms of the pits in the mucous membrane of the stomach to the submucous areolar tissue, are immense numbers of tubular glands. These are generally arranged in tolerably distinct groups surrounded by fibrous tissue; each group belonging to one of the polygonal depressions. The tissue which connects the tubes is dense, but not abundant. The researches of Wasmann, Todd and Bowman, Kölliker, Donders, Brinton, and others have shown marked differences in the anatomy of the glands and follicles of the stomach in different parts of the organ, which are particularly interesting, as they are supposed to correspond with differences in the function of various parts of the mucous membrane. There are, indeed, two distinct varieties of follicular glands: the gastric tubules, found throughout the organ, except in the pyloric portion; and the mucous follicles, found in the pyloric portion. These demand special consideration, as the

former are supposed to secrete the gastric juice and are active only during digestion, while the latter secrete a glairy mucus, which is not produced specially during digestion and which has no distinct digestive function with which we are acquainted.

Gastric Tubules.—These are the organs sometimes described under the name of peptic glands, or stomach-glands. In the large middle zone of the stomach, the tubes are simple, extending through the entire thickness of the mucous membrane. Their average length is about $\frac{1}{24}$ of an inch, and their diameter is from $\frac{1}{400}$ to $\frac{1}{300}$ of an inch. They are composed of a delicate, structureless, basement membrane, with the upper fourth or fifth lined with a continuation of the general columnar epithelial covering of the stomach, and the lower portion filled with, rather than lined by, hexagonal, soft, secreting cells, called the stomach or peptic cells. These cells have a nucleus and nucleolus, contain numerous rather large oval granules, and are about $\frac{1}{1200}$ of an inch in diameter. This is the general character of the tubes over the greater part of that portion of the mucous membrane which secretes the gastric juice. These tubes readily undergo post-mortem alteration, and, in the human subject, are only to be seen satisfactorily in the fresh stomachs of subjects who have died suddenly, having previously been in a condition of perfect health.

Around the cardiac opening of the stomach, are compound tubes, composed of essentially the same anatomical elements as the simple tubes, and undoubtedly endowed with the same function.[1] These commence by a short tube, or duct,

[1] Tubes of this kind are described and figured by Kölliker (*Manual of Human Microscopic Anatomy*, London, 1860, p. 320); but Sappey (*Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 120) attributes this to an illusive appearance produced by a super-position of different tubes, and asserts that such glands certainly do not exist in man. The appearances described by Kölliker have been often found by other observers, and there can be little doubt that compound follicles exist just around the cardia; but they probably are not found in other parts of the mucous membrane.

lined with columnar epithelium, occupying from one-third to one-half of the thickness of the mucous membrane. Below, it branches abruptly into from four to seven smaller secondary tubes, which are lined with glandular epithelium similar to that found in the simple glands. Generally the large-sized cells of glandular epithelium produce varicosities in the tubes which give them a peculiar and characteristic appearance—an appearance which is sometimes observed also in the simple tubes. In both of these varieties of tubes, we sometimes find granular matter and some fatty particles; though these are not always natural, as the delicate stomach-cells are frequently destroyed by the fluid in which the preparation is made, and break down into granular matter.

Mucous Follicles.—Near the pyloric extremity of the stomach, where the mucous membrane is decidedly paler than over the rest of the organ, the character of the tubular glands undergoes a decided change. In the first place, the orifices by which they open into the stomach are very much larger, being about twice the size of the openings of the true stomach-tubes. As the mucous membrane is here thicker than in other situations, the follicles are correspondingly longer. As a rule, they are compound; but they do not commence to divide until they have passed through about five-sixths of the thickness of the membrane, when they break up into from three to six small secondary tubes. The important peculiarity about these tubes is that many of them are lined throughout with columnar epithelium, and are everywhere deprived of the peculiar cells found in the true stomach-tubes.

In some recent investigations by Prof. J. C. Dalton into the anatomy of different parts of the stomach of the pig, most of which we were enabled by the kindness of Prof. Dalton to verify with him, the following results were arrived at:

"In the stomach of the pig the mucous membrane in the neighborhood of the pylorus is moderately thick and of a

light color. The villi upon its free surface are highly developed, being long, slender, often compound, and approximating in appearance, when simple, very much to the villi of the small intestines. The tubules of the mucous membrane, $\frac{1}{150}$ of an inch in diameter, run vertically through its whole thickness and terminate at various depths. The shorter ones are without branches, nearly straight, and terminate by simple rounded extremities. The longer ones give off several lateral branches near their lower extremity, the upper branches being longer, the lower ones shorter, the whole group collected into a little mass or lobule. These tubes are lined with epithelial cells, mostly of a cylindrical form, but of very small size, closely packed, and evidently glandular in character.

"In the neighborhood of the cardia, the mucous membrane is quite thin and pale, without any well-developed villous projections. In the superficial portion, the tubules are very wide cylinders, lined with large, clear, well-defined cells of cylinder-epithelium, branching below usually into two smaller tubes, also lined with cylinder-epithelium. These tubes become still further reduced in size until they are a little narrower than the tubules of the pyloric portion, when they become lined with small glandular epithelial cells, and terminate below in rounded extremities. The secreting tubules of this portion of the stomach are much shorter than those of the pyloric portion.

"In the middle portion of the stomach, especially along the great curvature, the mucous membrane is considerably thicker than elsewhere and is of a dark-red color. The villi upon its surface are perfectly distinct, though not so long and slender as in the pyloric portion. The gastric tubules are much longer than in any other part, and more closely bound together at the bottom, so that they are separated with much greater difficulty. They are rather wider than the other secreting tubules, and contain, besides the ordinary smaller epithelium, an abundance of large, rounded,

granular, and nucleated cells about three times the size of the glandular epithelial cells from either the cardiac or pyloric tubules. These cells appear to fill the cavity of the tubules, and give a varicose appearance to their lateral outlines."[1]

Todd and Bowman, who were among the first to point out the important differences in the glandular structures in different parts of the stomach, state that "for the most part, these prolongations of the cells—or, as we shall term them, *pyloric* tubes—end at length in very short and diminutive true stomach tubes: but we have likewise found them terminating in either flask-shaped or undilated extremities, lined throughout with the sub-columnar variety of epithelium."[2] Kölliker, who has also specially investigated this subject, states that the stomach-cells are entirely wanting in the pyloric tubes;[3] and Brinton, as the result of extended observations, makes the same assertion.[4] However this may be, the observations of Kölliker and Donders on the human stomach have shown that the active principle of the gastric juice can only be produced by the stomach-cells, and does not exist in the pyloric extremity.[5]

Todd and Bowman have found that the mucus which generally covers the membrane of the stomach, filling up the pits or depressions, is continued into the upper part of the tubes, which it nearly fills, as though it had gradually oozed

[1] Written communication to the author.

[2] TODD AND BOWMAN, *The Physiological Anatomy and Physiology of Man*, Philadelphia, 1857, p. 549.

[3] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 321.

[4] *Cyclopædia of Anatomy and Physiology*, London, 1859. Supplementary volume, p. 322.

[5] KÖLLIKER, *loc. cit.* In a note by Dr. Da Costa, the editor of the American edition (Philadelphia, 1854, p. 506), it is stated that Prof. Kölliker had an opportunity of examining the human gastric mucous membrane in a fresh and normal state in a case of suicide by drowning. In this case, the differences in the anatomy of the tubes in the cardiac, the middle, and the pyloric zone were fully established.

from the columnar cells at the sides, leaving a small central passage.[1]

Three observers, Middeldorph, Brücke, and Kölliker, almost simultaneously, each one ignorant of the observations of the others, noted in the submucous tissue the presence of a few involuntary muscular fibres surrounding the cœcal extremities of the stomach-tubes.[2] These are supposed to be active in discharging the contents of these tubes during the secretion of the gastric juice.

Closed Follicles.—In the substance of the mucous membrane, between the tubes and near their cœcal extremities, are occasionally found closed follicles, like the solitary glands and patches of Peyer of the intestines. These are not always present in the adult, but are generally found in children. They are usually most abundant over the greater curvature, though they may be found in other situations. In their anatomy they are identical with the closed follicles of the intestines, and do not demand special consideration in this connection.

Gastric Juice.

At the present day it seems profitless to argue the question of the existence of a digestive fluid in the stomach; and the discussions of the earlier physiologists as regards the possibility of the existence of a fluid capable of dissolving the articles of food have only an historical interest. It is important, however, to follow the experiments by which the existence and the properties of the gastric juice were brought to light, as the discovery of this fluid marks the commencement of our definite knowledge concerning the process of digestion.

In 1752, while the controversy between those who believed that the stomach simply triturated the food, and

[1] *Op. cit.*

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 180.

those who suspected the existence of a solvent fluid was at its height, Réaumur first obtained what is now known as the gastric juice, and demonstrated some of its solvent properties. In a paper presented to the Academy of Sciences of Paris, on the process of digestion in birds, he showed that meat enclosed in a tin tube so arranged as to permit the entrance of liquids, when forced into the stomach of a buzzard, became softened and partly digested after remaining in the organ for several hours. Substituting small pieces of sponge for the meat, he obtained a few grains of gastric juice, in which he noted a well-marked acid reaction; but the quantity obtained was not sufficient to allow of any satisfactory experiments on artificial digestion.[1] This was the first time that the presence of a solvent fluid in the stomach had ever been experimentally demonstrated, and the fluid was the first specimen of gastric juice ever obtained. The experiments on birds were repeated by Réaumur, in an imperfect manner, on dogs and sheep, with analogous results.

The celebrated observations of Stevens, in 1777, were even more conclusive with regard to the presence of solvent fluids in the alimentary canal. He had under observation a juggler, who, in his performances, was in the habit of swallowing stones and other hard articles. For the purpose of ascertaining whether food could be dissolved in the alimentary canal if removed from all triturating action, Stevens constructed little hollow balls of silver and of ivory, pierced with numerous small holes, and capable of being opened by a screw in the middle, which he caused the man to swallow after they had been filled with various articles.[2] After a number of hours, from thirty-six to forty-eight, the balls were passed by the anus entirely empty, except when they had been filled with hard grains, which were only a little

[1] RÉAUMUR, *Sur la Digestion des Oiseaux, Second Mémoire.—Histoire de l'Académie Royale des Sciences*, Paris, 1752, pp. 461–495.

[2] STEVENS, *De Alimentorum Concoctione*, Edinburgh, 1777, in SMELLIE'S *Thes. Med.*, quoted by TIEDMANN AND GMELIN, *op. cit.*, première partie, p. 365, note.

softened. A few years later, the experiments of Réaumur were reproduced by Spallanzani; who caused animals to swallow food contained in perforated tubes and obtained the gastric juice by means of sponges, extending the observations to dogs and cats and in some instances experimenting on his own person. He swallowed, for example, little netted bags of thread, and on one occasion a small perforated wooden tube, filled with food, which he found always passed empty by the anus.[1]

The experiments of Réaumur, Stevens, and Spallanzani demonstrated the existence of the gastric juice. They were followed by the elaborate investigations of Prout, Tiedemann and Gmelin, Leuret and Lassaigne, and others, by which various of the properties of this fluid were established;[2] but our definite knowledge of its most important physiological properties dates from the observations of Dr. Beaumont on the Canadian, Alexis St. Martin, who had a large fistulous opening into the stomach.[3] These observations were commenced in May, 1825, and were continued for a number of years. The first publication of them was in the *Philadelphia Medical Recorder*, in 1826.

Mode of obtaining the Gastric Juice.—The ingenious experiments of Dr. Beaumont upon the case of St. Martin gave an impulse to the study of digestion, and pointed out the way in which the action of the gastric juice could be inves-

[1] SPALLANZANI, *Opuscules de Physique, Animale et Végétale, Augmentés de ses Expériences sur la Digestion*, traduits par Jean Senebier, Pavie, 1787, tome ii. pp. 431, 483, 619, 642, and 645.

[2] LEURET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825. These authors give an analysis of the gastric juice, which corresponds pretty nearly with the analyses of the more recent physiological chemists. They noted the presence of lactic acid, hydrochlorate of ammonia, chloride of sodium, animal matter soluble in water, mucus, and phosphate of lime. (p. 113.)

[3] *Experiments and Observations on the Gastric Juice, and the Physiology of Digestion*, by WILLIAM BEAUMONT, M. D., Surgeon in the U. S. Army, Plattsburg, 1833.

tigated. The fact that Dr. Beaumont noted the action of human gastric juice upon all the ordinary articles of food enabled physiologists to compare with it the properties of the secretion obtained from the inferior animals, an indispensable condition in the study of the digestive fluids. In 1843, Blondlot published a treatise on digestion, in which he gave the results of experiments on dogs with fistulous openings into the stomach.[1] This observer is generally spoken of as the first to obtain the gastric juice by the establishment of a fistula into the stomach in the inferior animals; but Longet states that in December, 1842, Dr. Bassow read a paper before the Imperial Society of Naturalists of Moscow, which was published in the Bulletin for that year, in which he gave an account of a number of successful attempts to establish a gastric fistula in dogs.[2] In the animals operated upon by Bassow, the openings were not kept open by a canula, and he was much annoyed by their tendency to close. There is no reason to suppose that Blondlot was aware of the experiments of Bassow, which, as Longet remarks, were little known to physiologists, and, as far as we are aware, were not quoted in works on physiology before the publication of Longet's treatise in 1861. With some slight modifications in the operative manipulations, the method of Blondlot is the one now in common use.

The establishment of a permanent gastric fistula is now one of the simplest and most common of the physiological operations. The dog is the animal generally used; and from the fact that he is not very subject to peritonitis the operation almost always ends in recovery, and the animal can be trained so that the juice may be obtained in quantity and with great facility. The operative procedure which we have found most convenient is the following:

[1] BLONDLOT, *Traité Analytique de la Digestion*, Paris, 1843.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 190. Reference to the experiments of Bassow is also made by Milne-Edwards, in his elaborate work now in course of publication (*Leçons sur la Physiologie*, Paris, 1862, tome vii., p. 13).

It is best to choose a dog of medium size, young, but nearly, if not entirely full grown, in perfect health, and of good disposition. Bringing the animal under the influence of ether, he is to be held firmly on the back, and an incision about two inches in length is made in the median line into the abdominal cavity. This incision should be commenced from half an inch to an inch below the ensiform cartilage. Introducing the finger into the abdominal cavity, the stomach can readily be felt, especially if it be moderately distended; and with a pair of hooked, or bull-dog forceps, that portion of the stomach nearest the wound may be seized and drawn out of the abdomen. It is important to make the fistula into that portion of the anterior wall of the stomach which is nearest the wound, to avoid disturbance in the position of the viscera; and the organ is in the most favorable position for the operation if it be moderately distended with food.

A portion of the stomach being drawn out of the abdomen, a slit is made parallel to the longitudinal fibres, just large enough to admit the canula.

A silver canula, about an inch and a quarter in length, half an inch in diameter, and provided with a straight rim or flange at each end about half an inch in width, is now introduced into the stomach and firmly secured in place by a ligature surrounding it and passed in and out through the coats of the stomach near the lips of the wound, like the string of a purse. This canula may be single, or as suggested by Bernard, double, one-half screwing into the other so that it may be elongated to twice the length it has when closed. This is somewhat convenient, as the tube may be introduced elongated, and when the swelling of the parts has subsided, may be shortened by a key, so as not to project beyond the abdominal walls.

After the canula has been firmly fixed in the stomach, the tube, with one of its flanged ends projecting, should be drawn to the upper part of the opening in the abdomen, and

the wound closed by sutures passed through the integument, muscles, and peritoneum.

The dog will generally eat on the second or third day after the operation; and peritonitis—aside from the inflammatory action which agglutinates the stomach at the site of the operation to the walls of the abdomen—rarely follows. It is best to feed the animal sparingly a short time before operating, as there is some difficulty in seizing the stomach when it is entirely empty.

Having thus established a permanent fistula into the stomach, after the wound has cicatrized around the canula, the animal suffers no inconvenience, and may serve indefinitely for experiments on the gastric juice. Many physiologists have been in the habit of exciting the flow of this fluid by the introduction into the stomach of pieces of tendon, or hard indigestible articles, on the ground that the fluid taken from the fistula, under these circumstances, is unmixed with the products of stomach digestion; but it has been shown that the quantity and character of the juice is influenced by the nature of the stimulus which causes its secretion; and it is proper, therefore, to excite the action of the stomach by articles which are relished by the animal. For this purpose, lean meat may be given, cut into pieces so small that they will be swallowed entire, and first thrown into boiling water so that their exterior may become somewhat hardened. The cork is then removed from the tube, which is simply freed from mucus and *débris*, when the gastric juice will begin to flow, sometimes immediately, and sometimes in from three to five minutes after the food is taken. It will flow in clear drops or in a small stream for about fifteen minutes, nearly free from the products of digestion. At the end of this time it is generally accompanied with grumous matter, and the experiment should be concluded if it be desired simply to obtain the pure secretion. In fifteen minutes, from two to three ounces of fluid may be obtained from a good-sized dog, which, when filtered, is perfectly

clear; and this operation may be repeated three or four times a week without interfering with the quality of the juice or injuring the health of the animal.[1]

Although instances of gastric fistula in the human subject had been reported before the case of St. Martin and have been observed since that time, the remarkably healthy condition of the subject and the extended experiments of so competent and conscientious an observer as Dr. Beaumont have rendered this case memorable in the history of physiology. It is undoubtedly the fact that this is the only instance on record in which pure, normal gastric juice has been obtained from the human subject; and it served a most important purpose as the standard for comparison of subsequent experiments on the inferior animals. The details of this case, condensed from the monograph of Beaumont, are briefly the following:

Alexis St. Martin, a Canadian *voyageur* in the service of the American Fur Company, eighteen years of age, of good constitution and perfectly healthy, was wounded in the left side by the accidental discharge of a gun loaded with duck-shot. The wound was received on the 6th of June, 1822; and the muzzle of the gun was not more than a yard distant from the body. The contents of the gun entered posteriorly, carrying away integument and muscles from a space the size of the hand, with the anterior half of the sixth rib, fracturing the fifth rib, lacerating the lower portion of the left lobe of the lungs and the diaphragm, and perforating the stomach. The patient was seen by Dr. Beaumont twenty-five or

[1] Bernard recommends to make the fistula on the left side at the outer border of the rectus muscle. He introduces the canula forcibly through an opening into the stomach made as small as possible, and relies upon the contraction of the walls of the stomach around the tube to prevent the passage of matters into the peritoneal cavity. (*Leçons de Physiologie Expérimentale*, Paris, 1856, p. 385.) Unless this part of the operation be performed with great care and exactness, it is safer to employ the ligature. In collecting the juice, he simply fixes a bag of rubber to the canula after feeding the animal; but the fluid is obtained more satisfactorily by making the animal stand over a strong vessel, as a mortar. On several occasions we have had dogs so trained as to stand on the table for the proper time without requiring any attention.

thirty minutes after the accident, when the above facts were noted, and an opening into the stomach was discovered large enough to admit the forefinger. Extensive sloughing took place; and for seventeen days every thing that was swallowed passed out at the wound, and nourishment was administered by the rectum. In the spring of 1824, the wound had cicatrized, and the patient had perfectly recovered his health; but in the process of cure, seven pieces of cartilage had come away, and three or four inches of the sixth rib, with about half of the lower edge of the fifth rib, had been removed by an operation. The perforation into the stomach was irregularly circular in form, and about two and a half inches in circumference. This opening was closed by a protrusion of the mucous membrane of the stomach in the form of a valve, which could readily be depressed by the finger so as to expose the interior. This valve effectually prevented the discharge of the contents of the stomach, which had annoyed the patient previous to the winter of 1823–'24.

From May, 1825, to August of the same year, St. Martin was under the observation of Dr. Beaumont, and submitted to numerous experiments. At the end of that time, he returned to Canada, and was lost sight of for four years, during which time he married and became the father of two children, "worked hard to support his family, and enjoyed robust health and strength." He then came again under the observation of Dr. Beaumont, and continued in his service, doing the work of a common servant, until March, 1831. After this, he was under observation from time to time until 1836; all this time enjoying perfect health, with good digestion, and having become the father of several more children. The last published observations made upon this case were in 1856.[1]

[1] In the *Philadelphia Medical Examiner*, numbers for July and September, 1856, is an account of some experiments made on St. Martin in May of the same year. These observations were also published in the *Journal de la Physiologie*, Paris, 1858, tome i., p. 144 *et seq.*

The following was the method employed by Dr. Beaumont in extracting the juice: The subject was placed on the right side in the recumbent posture, the valve was depressed within the aperture, and a gum-elastic tube, of the size of a large quill, was passed into the stomach to the extent of five or six inches. On turning him upon the left side until the opening became dependent, the stimulation of the tube caused the secretion to flow, sometimes in drops and sometimes in a small stream. The quantity of fluid ordinarily obtained was from four drachms to an ounce and a half. The usual time for collecting the juice was early in the morning, before he had eaten. It was remarked that under these circumstances there was never an accumulation of gastric juice in the stomach, and its flow was only excited by the stimulus of the tube. It was also repeatedly observed that the introduction of alimentary principles, while the tube was in the stomach, produced an almost instantaneous increase in the flow.

Thanks to these opportunities for observing the action of the human stomach, followed by the experiments of Blondlot and others on the inferior animals, now so common, physiologists have become pretty well acquainted with the phenomena which attend the secretion of the gastric juice.

Secretion of the Gastric Juice.

As the earlier observers were unacquainted with the laws which regulate the production of secreted fluids as distinguished from those which contain only excrementitious principles, their ideas concerning the secretion of the gastric juice were necessarily indefinite. One of the most important facts developed by Beaumont was that the normal solvent fluid of the stomach is only produced in obedience to the stimulus of food, during the natural process of digestion. Recent advances in physiological chemistry have enabled experimenters to correct many errors in the observations of Beaumont concerning the properties and action of the gastric

juice, but his descriptions of the phenomena which accompany its secretion have been repeatedly verified.

During the intervals of digestion, the mucous membrane is comparatively pale, "and is constantly covered with a very thin, transparent, viscid mucus, lining the whole interior of the organ."[1] On the application of any irritation, or, better, on the introduction of food, the membrane changes its appearance. It now becomes red and turgid with blood; small pellucid points begin to appear in various parts, which are, in reality, drops of gastric juice; and these gradually increase in size until the fluid trickles down the sides in small streams. The membrane is now invariably of a strongly acid reaction, while at other times it is either neutral or faintly alkaline. The thin watery fluid thus produced is the true gastric juice. Though the stomach may contain a clear fluid at other times, this is generally abnormal, is but slightly acid, and does not possess the marked solvent properties characteristic of the natural secretion. It has been shown by Beaumont, and his observations have been repeatedly confirmed by experiments on the inferior animals, that the gastric juice is secreted in greatest quantity, and possesses the most powerful solvent properties, when food has been introduced into the stomach by the natural process of deglutition. Under these circumstances the stimulation of the mucous membrane is general, and secretion takes place from the entire surface capable of producing the fluid. When any foreign substance, as the gum-elastic tube used in collecting the juice, is introduced, the stimulation is local, and the flow of fluid is comparatively slight.[2] It has been also observed that the quantity immediately secreted on the introduction of food, after a long fast,

[1] BEAUMONT, *op. cit.*, p. 103.

[2] In endeavoring to obtain the pure gastric juice, Beaumont introduced a gum-elastic tube into the stomach in the morning, when the organ was entirely empty. Obtained in this way, it always required ten or fifteen minutes to collect from one and a half to two ounces of fluid. (*Op. cit.*, p. 106.)

is always much greater than when food has been taken after the ordinary interval.

While natural food is undoubtedly the proper stimulus for the stomach, and while, in normal digestion, the quantity of gastric juice is perfectly adapted to the work it has to perform, it has been noted that savory and highly seasoned articles generally produce a more abundant secretion than those which are comparatively insipid. An abundant secretion is likewise excited by some of the vegetable bitters. It was observed by Blondlot that the effects of alkalies and acids upon the secretion were entirely opposite. He states, as a general proposition founded on experiments, that while acids retard digestion, the action of alkalies is always to produce a great increase in the quantity of normal gastric juice.[1] He also makes the general statement that alkalies promote the flow of acid secretions, and *vice versâ;* supposing, on this principle, that the saliva tends to stimulate the flow of the gastric juice, and the acid secretion from the stomach, passing into the intestines, stimulates the flow of the alkaline fluids poured into this part of the alimentary canal. Of the fact that alkalies specially stimulate the gastric mucous membrane there can be no doubt; and it is probable that an abundant flow of saliva and its thorough incorporation with the food exerts, in this way, an important influence upon stomach-digestion.

Impressions made on the nerves of gustation have a marked influence in exciting the action of the mucous membrane of the stomach. Blondlot found that sugar, introduced into the stomach of a dog by a fistula, produced a flow of juice much less abundant than when the same quantity was taken by the mouth. To convince himself that this did not depend on the want of admixture with the alkaline saliva, he mixed the sugar with saliva and passed it in by the fistula, when the same difference was observed.[2] It is a cu-

[1] BLONDLOT, *Traité Analytique de la Digestion*, Paris, 1843, p. 219.
[2] *Op. cit.*, p. 221.

rious fact that in some animals, particularly when they are very hungry, the sight and odor of food will induce secretion of gastric juice.[1]

The gastric juice is probably one of the most sensitive of the secreted fluids to disturbing influences. It was remarked by Beaumont that a febrile condition of the system, the depression resulting from an excess in eating or drinking, and even purely mental conditions, such as anger or fear, vitiated, diminished, and sometimes entirely suppressed the secretion of the stomach. At some times the mucous membrane became red and dry, and at others it was pale and moist. In such morbid conditions, it is stated that drinks were immediately absorbed, but that food remained in the stomach undigested for twenty-four or forty-eight hours.[2]

It has also been shown by Bernard and others that various foreign substances circulating in the blood readily pass into the gastric juice; and that in cases of organic disease of the kidneys, and in animals in which the kidneys have been extirpated, urea is for a time eliminated by the mucous membrane of the stomach. The secretion is always arrested by inflammation or active irritation of the mucous membrane.

The influence of the nervous system on the secretion of gastric juice, exerted particularly through the pneumo-gastric nerve, is very marked and important, but its consideration belongs properly to the section on the nervous system.

After the food has been in part liquefied and absorbed and in part reduced to a pultaceous consistence, the secre-

[1] There is considerable difference in different dogs as regards the facility with which the flow of gastric juice may be excited. In some, the stomach is entirely free from fluid during the intervals of digestion, and the gastric juice can only be made to flow by the introduction of some digestible article. Dr. Dalton mentions an example of this kind (*Human Physiology*, Philadelphia, 1864, p. 137). In others, however, the reaction of the stomach is always acid, though it contains hardly any fluid during the intervals of digestion, and an abundant secretion of gastric juice may be induced by very slight stimulation.

[2] *Op. cit.*, pp. 107, 108.

tion of gastric juice ceases; the movements of the stomach having gradually forced that portion of the food which is but partially acted upon in this organ, or digested only in the small intestines, out at the pylorus. The stomach is thus entirely emptied, the mucous membrane becomes pale, its reaction loses its marked acid character, and becomes neutral or faintly alkaline.

Secretion in different parts of the Stomach.—The differences already noted in the anatomy of the mucous membrane of the stomach in different parts of the organ, point to the important question of a possible difference in the physiological action of the secretions of different parts, particularly the pyloric portion and the rest of the general surface. We can learn definitely but little with regard to this point from observations on the inferior animals, unless they be confirmed in the human subject. The observations, however, of Kölliker, Goll, and Donders on the pig, are very satisfactory, and subsequently were fully confirmed as regards the human subject. It is well known that an acidulated infusion of the mucous membrane of the stomach possesses, if properly prepared, all the digestive properties of the true gastric juice; and that this is not the case with similar infusions of the mucous membrane from any other parts. Kölliker, in experiments on artificial digestion made in conjunction with Dr. Goll, "on the gastric mucous membrane of the pig, clearly showed that the two kinds of glands entirely differ in respect of their solvent power; inasmuch as those with the round cells *dissolved* acidulated coagulated protein-compounds *in a very short time;* those with cylindrical epithelium, on the contrary, either did *not operate at all, or produced a slight effect only after a longer period.*"[1] The same author further states that these observations were confirmed by Donders and himself in the human stomach. In 1842, Mr. T. W. King noted the peculiar solvent action of the fluid

[1] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 521, and in the American edition, 1854, p. 508.

from the cardiac portion of the stomach. This part he found was always acid, while in other parts the reaction was variable. He states that after death, there is a distinct line from the right side of the cardiac opening to the great curvature, which marks the division between that portion which secretes the true gastric juice and has been acted upon after death, and that which does not produce a solvent fluid.[1]

Although the character of the secretion in different parts of the stomach is not the same in all animals, it must be admitted that in man, the mucous membrane of the stomach, in what may be called the pyloric zone, does not secrete the true, acid, solvent, gastric juice. In other words, this fluid is only produced in those portions of the stomach in which the mucous membrane is provided with tubes lined with cells of glandular epithelium, or what have been called the stomach-cells.

In most of the modern works on physiology, allusion is made to the probable quantity of gastric juice secreted in the twenty-four hours. The estimates on this point can be only approximative, even in the inferior animals, and they give no definite information concerning the normal quantity in the human subject. Bidder and Schmidt, Lehmann, Corvisart, and others have made calculations of the probable quantity, either by collecting the juice for a certain time and multiplying the quantity thus obtained by a number to represent the whole twenty-four hours, or by ascertaining the amount

[1] KING, *Observations on the digestive Solution of the Œsophagus, and on the distinctive Properties of the two Ends of the Stomach.—Guy's Hospital Reports*, London, 1842, vol. vii., p. 147 *et seq.* The observations of Mr. King, being generally upon subjects that had died of disease, are not as definite and conclusive as might be desired; but they are valuable as confirming the experiments of Dr. Wilson Philip on rabbits, who showed that the great pouch was the only part which was digested post mortem, when the animals were killed after a full meal (*An Experimental Inquiry into the Laws of the Vital Functions*, London, 1826, p. 131), and others who have also experimented on the inferior animals. In the celebrated paper of John Hunter on *Digestion of the Stomach after Death*, read before the *Royal Society* in June, 1772, it was noted that the softening was always at the great end (*Works*, Philadelphia, 1840, vol. ii., p. 147, and *Observations on certain parts of the Animal Œconomy*, London, 1792, p. 229).

of fluid required to digest a certain weight of food, and estimating from this the quantity necessary to dispose of all the food taken during the day. Both of these methods are manifestly incorrect. In the first, the intermittency of the secretion is not taken into account; and in the second, it is incorrectly assumed that digestion out of the body is accomplished precisely as it takes place in the stomach.

Dr. Beaumont was sometimes able to collect, in from ten to fifteen minutes, two ounces of pure gastric juice, simply by the stimulation produced by the gum-elastic catheter used in the operation; but he expressly states that in this case only a part of the mucous membrane is excited to secretion, while the flow is very much increased by the introduction of food by the mouth, which produces a general excitation of the secreting membrane. Assuming that two ounces can be collected, under the most favorable circumstances, in ten minutes, and that stomach-digestion continues for two hours,[1] the quantity secreted during the digestion of an ordinary meal would amount to twenty-four ounces. When we consider that the natural stimulus of food produces a general secretion, amounting to at least three or four times that produced by the simple introduction of the catheter, and that it is manifestly impossible to collect all that is secreted, even when nothing but the catheter has been introduced, it is evident that the entire quantity of gastric juice secreted during the digestion of a single meal must be very large; amounting, at a very moderate estimate, to from eight to ten pounds. Estimates, therefore, like those of Bidder and Schmidt, which put the quantity of gastric juice secreted in twenty-four hours by a healthy man of ordinary size at six thousand four hundred grammes, or about fourteen pounds,[2]

[1] In the latest published observations on St. Martin, by Professor F. G. Smith, of Philadelphia, it is stated that in no case does the food remain in the stomach more than two hours.—(*Expériences sur la Digestion.—Journal de la Physiologie*, Paris 1858, tome i., p. 146.)

[2] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. ii., p. 520.

are probably not exaggerated, though they are of necessity merely approximative.[1]

This enormous quantity of fluid daily secreted by the mucous membrane of the stomach would excite surprise were it not considered that after this fluid has performed its office in digestion, it is immediately reabsorbed, and but a small quantity of the secretion exists in the stomach at any one time. During digestion, a circulation of material is going on, in which the stomach is continually producing, out of materials furnished by the blood, a fluid which liquefies certain elements of the food, and, as fast as this is accomplished, is absorbed again by the blood, together with the principles that have been thus digested.

Composition of the Gastric Juice.

The gastric juice is mixed in the stomach with more or less mucus secreted by the lining membrane. When drawn by a fistula, it generally contains particles of food which have become triturated and partially disintegrated in the mouth, and is always mixed with a certain quantity of saliva which is swallowed during the intervals of digestion, as well as when the stomach is in a state of functional activity. By adopting certain precautions, however, the fluid may be obtained nearly free from impurities, except the admixture of saliva. The juice taken from the stomach during the first moments of its secretion, and separated from mucus and foreign mat-

[1] In many works on physiology, the question of the quantity of gastric juice secreted is very fully discussed. In the case of gastric fistula in a female, already referred to (see p. 177), the quantity of fluid secreted in twenty-four hours was estimated, from direct observations, at more than one-fourth the weight of the body. (SCHMIDT, *Ueber die Constitution des menschlichen Magensaftes.—Annalen der Chemie und Pharmacie*, Heidelberg, 1854, Bd. xcii., S. 43.) In this case, it was estimated that nearly nine thousand grains were secreted in an hour, and the calculation for the twenty-four hours was made from this quantity. It is not shown that the fluid thus collected was normal, either in quantity or quality; and even if it were, it is incorrect to suppose that its production in such quantity continues during the twenty-four hours. These, and indeed, all other estimates made on the same principle, are entitled to but little consideration.

ters by filtration, is a clear fluid, of a faint yellowish or amber tint, and possessing little or no viscidity. Its reaction is always strongly acid; and it is now a well established fact that any fluid, secreted by the mucous membrane of the stomach, which is either alkaline or neutral, is not the normal gastric juice.[1]

The specific gravity of the gastric juice in the case of St. Martin, according to the observations of Beaumont and Silliman, was one thousand and five;[2] but later, Dr. F. G. Smith found it in one instance, one thousand and eight, and in another one thousand and nine.[3] There is every reason to suppose that the fluid, in the case of St. Martin, was perfectly normal, and from one thousand and five to one thousand and nine may be taken as the range of the specific gravity of the gastric juice in the human subject. There is undoubtedly considerable variation as regards specific gravity in the inferior animals. In the dog, it has been usually found by Dalton as high as one thousand and ten.[4]

The gastric juice is described by Beaumont as inodorous, when taken directly from the stomach; but it has rather an aromatic and a not disagreeable odor when it has been kept for some time. It is a little saltish, and its taste is similar to "thin, mucilaginous water slightly acidulated with muriatic acid."[5] The gastric juice from the dog has something of the odor peculiar to this animal.

It has been found by Beaumont, in the case of the human

[1] As the gastric juice of the dog is the fluid generally used in experiments, it is proper to state that its reaction is always more strongly acid than the fluid from the human subject. It is unnecessary to discuss the opinions of physiologists anterior to the time of Beaumont, who disputed with regard to the reaction of the solvent fluid of the stomach, as they had no means of deciding what was the true gastric juice.

[2] Beaumont, *Observations, etc.*, p. 81.

[3] F. G. Smith, *Expériences sur la Digestion.—Journal de la Physiologie*, Paris, 1858, tome i., pp. 149, 152.

[4] Dalton, *On the Gastric Juice, and its Office in Digestion.—American Journal of the Medical Sciences*, October, 1854, p. 315.

[5] *Op. cit.*, p. 85.

subject, and by others who have experimented on the gastric juice of the lower animals, that this fluid, if kept in a well stopped bottle, will retain its chemical and physiological properties for an indefinite period. The only change which it undergoes is the formation of a pellicle, consisting of a vegetable confervoid growth, upon the surface, some of which breaks up and falls to the bottom of the vessel, forming a whitish, flocculent sediment. We have now a specimen of gastric juice which was taken from a dog with a gastric fistula in January, 1862. It has no putrefactive odor, and is apparently in the same condition as when it was first drawn. In addition to this remarkable faculty of resisting putrefaction, this process is arrested in decomposing animal substances, both when taken into the stomach and when exposed to the action of the gastric juice out of the body.

There are on record no minute quantitative analyses of the human gastric juice, except those by Schmidt, of the fluid from the stomach of a woman with gastric fistula;[1] and

[1] For analyses by SCHMIDT of two specimens of gastric juice taken from the stomach of this woman, see MILNE-EDWARDS, *Leçons sur la Physiologie*, Paris, 1862, tome vii., p. 42.

In nine analyses of the gastric juice of the dog, when the saliva had been previously shut off from the alimentary canal, Bidder and Schmidt found the following to be the mean composition (*Die Verdauungssäfte*, Leipzig, 1852, S. 61):

Table of Solid Constituents of the Gastric Juice of the Dog.

Ferment, etc.	17·127
Free hydrochloric acid	3·050
Chloride of potassium	1·125
Chloride of sodium	2·507
Chloride of calcium	0·624
Chloride of ammonium	0·468
Phosphate of lime	1·729
Phosphate of magnesia	0·226
Phosphate of iron	0·082
	26·938

In another series of three experiments, in which the saliva was allowed to pass into the stomach, the proportion of free acid was 2·337, and the proportion of organic matter was somewhat increased. (*Op. cit.*, p. 70.)

in this case there is reason to suppose that the secretion was not normal. The analysis of the gastric juice of St. Martin by Berzelius was not minute. The analyses of Schmidt give less than six parts per thousand of solid matter; while Berzelius found over twelve parts per thousand. In all the comparatively recent analyses, there have been found a free acid or acids; a peculiar organic matter, generally called pepsin; and various inorganic salts, among which may be mentioned as most important, the chlorides of sodium, potassium, and calcium, with the phosphates of lime, magnesia, and iron. Of these constituents, the salts possess little physiological importance compared with the organic matter and the acid principles.

Organic Principle of the Gastric Juice.—This principle, called pepsin or gasterase, is an organic nitrogenized body, peculiar to the gastric juice; and, as we shall see further on, is essential to its digestive properties. When the gastric fluid was first obtained, even by the imperfect methods employed anterior to the observations of Beaumont and of Blondlot, an organic matter was spoken of as one of its constituents. In the rough analyses given by Leuret and Lassaigne, in 1825, an "animal matter soluble in water" is mentioned;[1] Tiedemann and Gmelin speak of "an animal matter insoluble in alcohol, but soluble in water," which they regarded as salivary matter, and another animal matter, soluble in alcohol (osmazome);[2] and, finally, in a letter to Dr. Beaumont, Dr. Dunglison states that in conjunction with Professor Emmet, of the University of Virginia, he found in a specimen of gastric juice taken from St. Martin "an animal matter, soluble in cold water, but insoluble in hot."[3] This principle

[1] LEURET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 113.

[2] TIEDEMANN ET GMELIN, *Recherches Expérimentales Physiologiques et Chimiques sur la Digestion*, Paris, 1827, première partie, p. 168.

[3] BEAUMONT, *Experiments and Observations on the Gastric Juice, and the Physiology of Digestion*, Plattsburg, 1833, p. 78.

was not mentioned by the authors just cited as essential to the solvent action of the gastric juice; but experiments on artificial digestive fluids by Eberle, Schwann and Müller, Wasmann, and others, demonstrated that acidulated infusions of the mucous membrane of the stomach, possessing all the physiological properties of the gastric juice, contained an organic matter, first isolated by Wasmann, on which the solvent powers of these acid fluids seemed to depend. The experiments of Schwann and Müller upon the action of artificial digestive fluids are very interesting, and corrected the mistake made by Eberle, who supposed that an organic substance, with the same properties as that made from the stomach, could be extracted from any of the mucous membranes.[1] Mialhe, who has obtained this substance in great purity by the process recommended by Vogel, describes the following properties as characteristic of the organic matter in artificial gastric juice. Dried in thin slices on a plate of glass, it is in the form of small, grayish, translucent scales, with a faint and peculiar odor, and a feebly bitter and nauseous taste. It is soluble in water and in a weak alcoholic mixture, but is insoluble in absolute alcohol. A solution of it is rendered somewhat turbid by a temperature of 212° Fahr., but it is not coagulated, though it loses its specific properties. It is not affected by acids, but is precipitated by tannin, creosote, and a great number f the metallic salts.[2] This substance dissolved in water slightly acidulated possesses, in a very marked degree, the peculiar solvent properties of the gastric juice; but it has been found by Payen and Mialhe not to be so active as the principle extracted from the gastric juice itself, which is described by Payen under the name of gasterase.[3] In the abattoirs of Paris, Mialhe collected from the

[1] MUELLER, *Manuel de Physiologie*, traduit par Jourdan, Paris, 1851, tome i., p. 465.

[2] MIALHE, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 39.

[3] PAYEN, *Note sur le Principe actif du Suc Gastrique.—Comptes Rendus*, Paris, 1843, tome xvii., p. 654 *et seq.*

secreting stomachs of calves as they were killed, from six to ten pints of gastric juice; and from this he extracted the pure pepsin by the process recommended by Payen, which consists merely in one or two precipitations by alcohol. This substance he found to be identical with the principle obtained by Payen from the gastric juice of the dog. Its action upon albuminoid matters was precisely the same as that of pepsin extracted from artificial gastric juice, except that it was more powerful.

Source of the Acidity of the Gastric Juice.—Réaumur and Spallanzani recognized that the fluid from the stomach has, at certain times, an acid reaction; and subsequent observations have confirmed this fact, and shown that this reaction is invariable during digestion. But although the most distinguished and skilful chemists of the day have attempted to ascertain the source of this acidity, from Prout, in 1823, to Blondlot, in 1858, embracing Leuret and Lassaigne, Tiedemann and Gmelin, Berzelius, Chevreuil, Bidder and Schmidt, Dumas, Lehmann, Bernard and Barreswil, with a host of others, the question has not yet received a solution which is generally accepted. It would be inconsistent with the plan of this work to discuss all the opinions which have from time to time been expressed upon this subject, or to attempt to criticise the various processes employed by different chemists in the analyses they have brought forward in support of their views. The discussion will be confined to the question of the existence of one or more of three acid principles; viz., free hydrochloric acid, free lactic acid, and the acid phosphate of lime.

In 1823, Prout examined the fluid from the stomachs of rabbits which had been fed a short time before death, and demonstrated, apparently, the presence of free hydrochloric acid. The method employed in these analyses was to estimate in a certain portion of a watery extract of the contents of the stomach the total amount of fixed chlorides (or muriates as

they were then called); in another portion, the total amount of hydrochloric acid, both free and combined; and in another the total amount of free acid. By this process, the estimate for the free acid was corrected by subtracting the estimated proportion of fixed acid from the proportion of acid, free and combined. An abundance of hydrochloric acid was also indicated by Prout in the acid matters vomited in certain cases of dyspepsia.[1]

The method made use of by some of those who profess to have found free hydrochloric acid in the gastric juice has been to subject the fluid to distillation, testing the acid fluid which passes over, with nitrate of silver. This was the method employed by Dunglison and Emmet;[2] but the experiments of Bernard and Barreswil on the gastric juice from dogs, and the more recent observations of Dr. F. G. Smith on the gastric juice from St. Martin, have shown that this process is really of little value. The following observations by Bernard and Barreswil show conclusively that although hydrochloric acid may be obtained from gastric juice by distillation, it does not necessarily exist in the fluid in a free state; a very important consideration in a question in which every thing depends upon the absolute accuracy of modes of analyses:

In subjecting the gastric juice of the dog to distillation at a low temperature, with all the necessary precautions, it was found that the first products did not present an acid reaction. It was at first thought that this would be ground for the exclusion of hydrochloric acid, which is considered to be volatile; but it was found that in the distillation of water which had been slightly acidulated with hydrochloric acid, the first products were neutral, and the acid was only disengaged in the fluid which passed over toward the last periods

[1] PROUT, *On the Nature of the Acid and Saline Matters usually existing in the Stomachs of Animals; read Dec.* 11, 1823.—*Philosophical Transactions*, London, 1824, p. 45 *et seq.*

[2] BEAUMONT, *op. cit.*, p. 78.

of the process. In again distilling the gastric juice, it was found that the product was neutral, presenting no precipitate with the nitrate of silver, until about four-fifths of the fluid had passed over; that afterward, the fluid which passed over was distinctly acid, but did not precipitate with the salts of silver; and "finally, only toward the last instants, when there only remained a few drops of gastric juice to evaporate, the acid liquid which was produced gave a marked precipitate with the salts of silver, which was not dissolved by concentrated nitric acid."[1] It was found that the addition to the gastric juice of a small quantity of oxalic acid produced a marked opacity due to the formation of the insoluble oxalate of lime, while an equal quantity of the same reagent produced no opacity in water containing a proportion of two thousandths of hydrochloric acid, to which chloride of calcium had been added. From this experiment, Bernard concluded that the hydrochloric acid in the gastric juice exists in the condition of a chloride, and not in a free state.

Prof. F. G. Smith, who had an opportunity of examining the gastric juice from St. Martin, in 1856, took the fluid from the stomach after two ounces of dry bread had been chewed and swallowed, and subjected it to distillation. The first fluid which passed over was neutral, and the residue, after the temperature had been somewhat raised, produced a slight precipitate with the nitrate of silver, which was soluble in ammonia. In another experiment, a mixture of lactic acid and chloride of sodium in solution was subjected to distillation, and the product formed a slight precipitate with the nitrate of silver. The precipitation, in this instance, was attributed to the passage of a small quantity of chloride of sodium with the vapors, and it is to this, also, that he attributes the opalescence of the products of distillation of the

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, tome ii., p. 395; and BERNARD, VILLEFRANCHE ET BARRESWIL, *Sur les Phénomènes Chimiques de la Digestion* (deuxième mémoire).—*Comptes Rendus*, Paris, 1844, tome xix., p. 1284 *et seq.*

gastric juice, when treated with the nitrate of silver.[1] These experiments are of great interest in so far as they confirm the observations of Bernard, Villefranche, and Barreswil on the gastric juice of the dog.

The experiments of Lehmann on this point are even more conclusive. He found that pure gastric juice, when evaporated *in vacuo*, develops hydrochloric acid; but he also found that chloride of calcium is decomposed during evaporation with lactic acid *in vacuo*, and attributes the generation of hydrochloric acid in the gastric juice to the decomposition with this salt, and not the chloride of sodium, as was thought by Bernard, Villefranche, and Barreswil.[2]

These observations explain perfectly the presence of hydrochloric acid in liquids obtained by distillation of the gastric juice, without supposing that this acid, in a free state, is one of its normal constituents. But this is not the only ground on which the opinion that the hydrochloric is the free acid of the gastric juice is based. Physiologists of the present day who hold to this view rely chiefly on the recent examinations of the gastric juice of the dog by Bidder and Schmidt. It remains now to see whether the observations of Schmidt, which apparently demonstrate the existence of a proportion of chlorine not to be accounted for except under the supposition that it exists in the form of free hydrochloric acid, are conclusive, when opposed to the facts which are supposed to be inconsistent with the existence of free hydrochloric acid in the gastric secretion. The method employed by Bidder and Schmidt is, in brief, the following:[3]

The juice was taken from dogs that had been fasting for from eighteen to twenty hours, the food having previously been either animal or vegetable, the gastric juice in both cases being identical. To prevent the admixture of saliva,

[1] F. G. SMITH, *Expériences sur la Digestion.—Journal de la Physiologie*, Paris, 1858, tome i., p. 149 *et seq.*

[2] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 93.

[3] BIDDER UND SCHMIDT, *Die Verdauungssäfte*, Leipzig, 1852, S. 44 *et seq.*

all the salivary ducts were tied before the fluid was taken from the stomach.

The first step was to take about one hundred grammes of cold gastric juice, strongly acidulated with nitric acid, and precipitate it with nitrate of silver. The chloride of silver, free from organic mixture, was then separated by filtration and weighed, the total quantity of chlorine being calculated therefrom. After having precipitated the excess of the salt of silver in the filtered fluid by hydrochloric acid, the liquid was calcinated in a porcelain vessel, and the total quantity of bases estimated. Having thus obtained the proportion of bases and the total quantity of chlorine, it is evident that if this quantity be more than sufficient to saturate the bases, the chlorine must exist in some other form, which is supposed by Schmidt to be that of hydrochloric acid. It was found, indeed, that the quantity of chlorine was greater than the equivalent of the bases estimated.

The second step was to determine, by saturating the acid of the gastric juice with potassa, lime, or baryta, the proportion of free acid. It was found by this process that the quantity of free acid *nearly* corresponded with the excess of chlorine over the quantity estimated as combined with bases in the previous experiment.

In this process, the ammonia is necessarily lost during calcination; but in subsequent experiments, this substance was found to be constantly present, but in inconsiderable quantity. It was also assumed to be experimentally demonstrated that no organic acid, with the elements, C.H.O., existed in the gastric juice, except in infinitesimal quantity.

These experiments afford the strongest arguments in favor of the view that hydrochloric acid is the free acid of the gastric juice; but on the other hand, facts have been brought forward, some of which have already been referred to, which show that this acid cannot here exist in a free state.

One of the most important of these facts is, that the addition of a small quantity of oxalic acid to gastric juice produces

a precipitate of the insoluble oxalate of lime, which does not take place in the presence of free hydrochloric acid, even when it exists in very minute quantity. No one has denied that this reaction always takes place in the gastric juice; but, in this fluid, is it inconsistent with the presence of a small quantity of hydrochloric acid? We have found that the addition of two drops of ordinary hydrochloric acid to half a fluid ounce of gastric juice does not prevent the precipitation of the oxalate of lime, which, in the single observation referred to, was only prevented when the quantity of acid was increased to five drops. On adding oxalic acid to fresh urine, the precipitate of oxalate of lime was marked; but after the addition of two drops of ordinary hydrochloric acid, this reaction did not take place. Taken in connection with the fact that many of the ordinary chemical reactions are prevented or modified in fluids containing organic substances, this would lead us to inquire whether free hydrochloric acid may not exist in small quantity in the gastric juice, and, as an exceptional phenomenon, the reaction between the oxalic acid and the soluble salts of lime still take place; or whether the acid may not unite with the organic principle, forming, as was suggested by Schiff, chlorohydropeptic acid. In support of this latter view, it is to be remembered that Mulder has formed combinations of organic principles with various of the mineral acids, such as the sulphuric and the hydrochloric. In these compounds, the acid character remains, but the ordinary reactions of the acid are lost. For example, in a compound of sulphuric acid, called by Mulder, sulpho-proteic acid, the precipitations with baryta and lime do not take place.[1]

[1] These compounds of mineral acids with organic principles have been very little studied. In view of the accurate researches of Bidder and Schmidt, and the fact that many of the properties of fluids containing free hydrochloric acid are wanting in the gastric juice, Longet, after a full and candid discussion of the whole question, admits the possible existence of an acid compound of pepsin and hydrochloric acid, characteristic of the gastric juice; but he contends for the existence, in addition, of a certain proportion of a free organic acid, which he

With the abundant opportunities which have been presented for the chemical study of the gastric juice, not only in the inferior animals, but in man, and in view of the numerous elaborate researches into the nature of this fluid by the most skilful physiological chemists of the day, it is a matter of surprise that the question of the existence of free hydrochloric acid, or its condition as regards combination with the organic matter, is not settled. It certainly cannot now be regarded as settled beyond question. If, as is supposed by Bidder and Schmidt, there be a proportion of chlorine which cannot be accounted for by the quantity of ordinary bases in the gastric juice, it probably does not exist as free hydrochloric acid, but is in some way united with organic matter.

In 1786, Macquart indicated the presence of lactic acid in the gastric juice of the calf; attributing to free phosphoric acid, the acidity of the gastric juice of the ox and the sheep.[1] Since then there have been numerous analyses in which this principle has been said to be found. Among those who early adopted this view, may be mentioned Chevreul, Graves, Leuret, and Lassaigne. After the analyses by Prout, in 1823, and the observations of Beaumont on the fluid obtained from St. Martin, and until the publication of the experiments of Bernard, Villefranche, and Barreswil, in 1844, the hydrochloric was generally supposed to be the free acid of

supposes to be the lactic acid. (*Traité de Physiologie*, Paris, 1861, tome i., p. 203.)

[1] MACQUART, *Mémoire sur le Suc Gastrique des Animaux Ruminants.—Mémoires de la Société Royale de Médecine*, Paris, 1786, p. 355 *et seq.* In a pound of gastric juice from the calf, obtained from animals just killed, Macquart found forty-eight grains of lactic acid (p. 377). It is probable that the large quantity of acid thus obtained was derived in part from the milk taken into the stomach of the animal; especially as Macquart mentions that sugar was likewise found, which certainly is not a normal constituent of the gastric juice. At the time of the observations of Macquart, the formation of lactic acid from sugar was not known. In fact, it was only in 1780 that this acid was first described by Scheele; and it was many years before its formation from sugar, muscular tissue, etc., was described.

the gastric juice.[1] It is chiefly on the last-named observa tions—which have been supported by Bernard in his later publications[2] and by the confirmatory experiments of Lehmann and others—that those who admit the presence of free lactic acid in quantity in the gastric juice rest their belief.

We have already referred to the experiments of Bernard, which show that an artificial fluid containing chloride of sodium and lactic acid in solution behaves, during distillation, in every way like the natural gastric juice. These show also how hydrochloric acid may be produced during the last period of the distillation by decomposition of the chlorides. We have seen that this observation was confirmed by Lehmann, who noted the same reaction during evaporation at the ordinary temperature, *in vacuo*, though he supposed the action in the gastric juice to be upon the chloride of calcium instead of the chloride of sodium. Lehmann found in the acid residue, free lactic acid, lactate of lime, and alkaline chlorides. Bernard and Lehmann have brought forward other experimental facts to prove that the gastric juice contains lactic acid. If starch be boiled in a solution containing hydrochloric acid, it soon loses its property of forming a blue compound with iodine; while if it be boiled with lactic acid, no such change is observed. If starch be boiled with a solution containing hydrochloric acid, to which has been added a soluble lactate in excess, it remains unaltered; which shows, according to Bernard, that hydrochloric acid in a free state cannot exist in the presence of an excess of a salt of lactic acid. By similar experiments, the same observer assumes to prove that the existence of hydrochloric acid is inadmissible in the presence of a phosphate or an acetate in excess.[3] Lehmann has found that starch boiled with gastric juice retains the property of being colored blue by iodine.[4]

[1] *Loc. cit.*

[2] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 393 *et seq.*

[3] *Op. cit.*, p. 398.

[4] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, p. 93.

These experiments are considered by Bernard as positive proof that the acid of the gastric juice is the lactic; and the fact "seems to him to be at the present day beyond contestation." The facts adduced by Lehmann, however, are even stronger. By operating upon a large quantity of gastric juice, he has been enabled to form the lactates in such quantity that he was enabled to subject them to ultimate analysis, and determine positively the nature of the acid. He found that the acid had the composition of lactic acid formed from sugar, and not that of the acid formed from the juice of the muscular tissue.[1]

In view of the facts above mentioned, and the somewhat uncertain basis on which the supposition of the presence of free hydrochloric acid is founded, it seems almost certain that the principal free acid of the gastric juice is the lactic. It is important to remember that while the experiments of Bernard and Lehmann were made on gastric juice from the dog, they have been confirmed, in their essential particulars, by the recent observations of Prof. F. G. Smith on the normal gastric juice from the human subject.[2]

It now remains only to discuss the question of the existence in the gastric juice of the acid phosphate of lime, to the exclusion altogether of free acids; a theory first proposed by Blondlot in 1843, and entertained and defended by him, as late as 1858, notwithstanding the fact that this view has met with no favor in the physiological world.[3]

[1] *Loc. cit.*

[2] F. G. SMITH, *Expériences sur la Digestion.—Journal de la Physiologie*, Paris, 1858, tome i., p. 144; and *Philadelphia Medical Examiner*, July and September, 1856.

[3] In a paper devoted entirely to the question of the acid principle of the gastric juice (*Nouvelles Recherches Chimiques sur la Nature et l'Origine du Principe Acide qui domine dans le Suc Gastrique*, Paris, 1851, p. 4), Blondlot acknowledges that he remains almost alone in his opinion; for, with the exception of Dumas, "who, while admitting the presence of free lactic acid, tacitly declares that the existence of the biphosphate of lime cannot be mistaken," all authors oppose his view. In the page referred to by Blondlot (DUMAS, *Traité*

To Blondlot belongs the rare merit of having been one of the first, if not the very first, to propose and execute an experiment by which the normal gastric juice could be obtained in quantity from a living animal. In his first analysis of the fluid thus obtained, he denied the existence of any acid principles except the biphosphate of lime. This view he holds at the present day; and notwithstanding the elaborate researches of the most distinguished physiological chemists, in all of which a free acid of some kind has been recognized, still ardently defends his original position. The question of the existence in the gastric juice of the acid phosphate of lime, to the exclusion of free acids, may be discussed in a few words.

Assuming that the gastric juice contains a free acid, a view which the arguments of Blondlot fail to disprove, the question arises whether the biphosphate of lime may not also exist in this fluid. On this point there can be no doubt. All the modern analyses of the gastric juice give the phosphate of lime as one of its constituents; and Blondlot justly remarks that it is strange to see, in certain analyses, the neutral phosphate of lime and hydrochloric or lactic acid put down as existing together, as though the phosphoric acid were able to retain the two equivalents of the base in the presence of either of these two acids.[1] The fact is, that basic phosphate of lime ($3CaO,PO_5$), a salt insoluble in pure water, but soluble in acid solutions, is invariably decomposed in the presence of acids as powerful as the hydrochloric or the lactic. It then loses two equivalents of the base, and is transformed into the acid phosphate ($CaO+2HO,PO_5$).

After having discussed the question of the existence of the biphosphate in two elaborate memoirs, one published in

de Chimie, Paris, tome viii., p. 604), it is only stated that the acid reaction of the gastric juice is not due exclusively to the biphosphate of lime, as was recently advanced by Blondlot, and the existence of this principle is nowhere positively admitted.

[1] Blondlot, *Nouvelles Recherches sur la Digestion.—Journal de la Physiologie*, Paris, 1858, tome i., p. 310, note.

1843 and the other in 1851, in a third, Blondlot regards the presence of this principle in the gastric juice as conclusively established by the fact that it forms a precipitate of the neutral phosphate of lime with pure lime-water; the precipitate, as he assumes, being formed by the neutralization of the acid phosphate.[1] This conclusion is undoubtedly perfectly legitimate; and there can be no doubt but that the biphosphate of lime always exists in the gastric juice, in greater or less quantity. This principle must be put in the place of the neutral phosphate, which is given by most authors, for the latter salt cannot exist in a fluid containing free hydrochloric or lactic acid, either of which acids would immediately appropriate the excess of the base. That a free acid exists in the gastric juice in a proportion more than sufficient to simply act upon the neutral phosphates—which would then form lactates and leave the biphosphate as the single acid principle—is shown by the fact that the gastric juice will dissolve and act upon an excess of the neutral phosphate of lime.[2] This fact in itself is sufficient to show that the gastric juice does not depend for its acidity entirely on the biphosphate of lime.

There can be no doubt of the constant presence of the acid phosphate of lime in the gastric juice, at least in the dog; and its quantity is undoubtedly increased in this animal during the digestion of bones, by the action of the acid fluid upon their phosphatic constituents; but the arguments of Blondlot against the existence of a free acid have little or no weight. One of those on which most stress is laid is that the gastric juice does not act upon the carbonates; which

[1] *Loc. cit.*, p. 309.

[2] BERNARD, VILLEFRANCHE ET BARRESWIL, *Sur les Phénomènes Chimiques de la Digestion* (deuxième mémoire).—*Comptes Rendus*, Paris, 1844, tome xix., p. 1284. These authors state that the gastric juice will dissolve the neutral phosphate of lime, which is insoluble in the biphosphate (p. 1285); but this is not, as they supposed, an argument against the existence of the biphosphate, for it has long been well known that the neutral phosphate of lime is readily dissolved in acid liquids.

would undoubtedly be the case if it contained a free acid. The simple reply to this is that there is sufficient evidence to show that it is not the fact. Melsens, using a specimen of fluid obtained by Blondlot from the dog and given to Dumas, found that seventy-three grammes of juice dissolved, in twenty-four hours, 0·108 of a gramme of calcareous spar (crystallized carbonate of lime). He confirmed this observation by several experiments, so that there can be no doubt as to its accuracy.[1]

It is plain, therefore, that while the acid phosphate of lime has been shown to be a constant constituent of the pure gastric juice, contributing, in a certain degree, to its acidity, it is not by any means to be regarded as the sole acid principle; the phosphate probably existing in this form by virtue of the presence in this fluid of a free acid.

On what does the Acidity of the Gastric Juice depend?

This is the simple question to which the foregoing discussion naturally leads; and it is one which can be answered almost with positiveness, though it is not settled to the satisfaction of all physiologists, and there are some conflicting observations which can be harmonized only by new researches.

Aside from the conditions under which acids, such as the butyric, acetic, or the lactic, are developed from articles of food taken into the stomach, the evidence is strongly in favor of free lactic acid as the principle on which the gastric juice mainly and constantly depends for its acidity. There also exists a certain proportion of the biphosphate of lime; and this is the only condition in which a phosphate of lime can exist in the presence of free lactic acid.

The observations of Bidder and Schmidt indicate, apparently, a quantity of chlorine in the gastric juice not to be

[1] Melsens, *Recherches sur l'Acidité du Suc Gastrique.—Comptes Rendus*, Paris, 1844, tome xix., p. 1289 *et seq.*

accounted for by the proportion of bases obtained by ultimate analysis. There is evidence sufficiently positive to show that there is no hydrochloric acid in the gastric juice, in a condition which allows the fluid to present the reactions which are observed when this acid exists in a free state. If there be any hydrochloric acid not in combination with metallic bases, it is united with organic matter in such a way as to prevent the manifestations of its ordinary properties, excepting that of acidity. The fact that some of the mineral acids can be made to unite in this way with albuminoid substances lends color to this supposition; although further investigations are necessary to demonstrate that this takes place in the gastric juice.

Ordinary Saline Constituents of the Gastric Juice.—It has been experimentally demonstrated that artificial fluids, containing the organic principles of the gastric juice and the proper proportion of free acid, are endowed with all the digestive properties of the normal secretion from the stomach; and that these properties are rather impaired when an excess of its normal saline constituents is added, or when the relation of the salts to the water is disturbed by concentration. Boudault and Corvisart evaporated two hundred grammes of the gastric juice of the dog to dryness, and added to the residue fifty grammes of water. They found that the fluid thus prepared, containing four times the normal proportion of saline principles, did not possess by any means the energy of action on alimentary substances of the normal secretion.[1] These facts have led physiologists to attach little importance to the ordinary saline principles found in the gastric juice.

In the various analyses of the pure juice from the human subject and the inferior animals, particularly dogs, chemists have discovered the chlorides of sodium, calcium, potassium,

[1] Quoted by LONGET, *op. cit.*, tome i., p. 204.

and ammonium, and the phosphates of lime (necessarily in the form of the biphosphate), magnesia, and a small proportion of the phosphate of iron. Of these principles, the chloride of sodium has always been found to exist in greatest abundance.

CHAPTER IX.

ACTION OF THE GASTRIC JUICE IN DIGESTION.

Constituents on which the activity of the gastric juice depends—Action of the gastric juice upon meats—Action upon albumen, fibrin, caseine, and gelatine —Action upon vegetable nitrogenized principles—Albuminose, or peptones—Action of the gastric juice on fats—Action on saccharine and amylaceous principles—Duration of stomach-digestion—Digestibility of different aliments in the stomach—Action of the gastric juice upon the coats of the stomach—Circumstances which influence stomach-digestion.

In treating of the composition of the gastric juice, frequent allusion has been made to its solvent action in digestion, and the constituents on which this property depends. Certain of the principles most readily attacked by this fluid are acted upon by weak acid solutions containing no organic matter; but though some physiologists have been disposed to regard the acts of solution which take place in the stomach as dependent merely on the presence of a free acid, it is now well established that the presence of a peculiar organic principle is an indispensable condition to the performance of real digestion by the gastric fluid.[1] The experiments of Mialhe,[2]

[1] Bouchardat et Sandras, *Recherches sur la Digestion.—Annales de Chimie et de Physique*, 1842, 3me serie, tome v., p. 478 *et seq.* These authors attempted to show that a feeble acid fluid was capable of dissolving fibrin and gluten, but they failed to prove that this solution was similar to the process which takes place in digestion. The view that the digestion of certain principles in the stomach is due solely to the action of a free acid was also entertained by Tiedmann and Gmelin. (*Op. cit.*)

[2] Mialhe, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 114 *et seq.* In these experiments, Mialhe was only carrying out the idea of Dumas, who believed that two agents exist in the gastric juice; viz., "the acid

undertaken with the view of showing that the acid simply prepared the albuminoids by permeating them and causing them to swell up and become gelatiniform, do not show that solution of these principles, even after such preparation, can be accomplished by a neutral solution of the organic principle of the gastric juice. The view thus advanced by Mialhe was completely disproved by the observations of Longet, who showed that when the solution was neutralized, some of the acid fluid always remained in the substance of the nitrogenized principle which had been subjected to its action; and thus, when pepsin was added, the substance digested was really permeated by a fluid containing both the organic principle of the gastric juice and an acid. When, on the other hand, the fibrin, which was the nitrogenized substance used in the experiments, was removed from the neutralized solution, cut into slices, and washed, so as to remove all trace of acid, the neutral solution of pepsin had no action upon it.[1]

It has, indeed, been fully established that fluids containing the organic principle of the gastric juice have no digestive properties unless they also possess the proper degree of acidity; and it is as well settled that fluids containing acids alone have no action on albuminoids similar to that which takes place in digestion; and that when these principles are dissolved by them it is simply accidental.

It is a curious fact that the presence of any one particular acid does not seem essential to the digestive properties of the gastric juice, so long as the proper degree of acidity is retained. In the experiments of Bernard, Villefranche, and Barreswil, after saturating the gastric juice with neu-

which softens and swells up the nitrogenized matter; the pepsin or the chymosine which determines its liquefaction by a phenomenon analogous to that of the action of diastase on starch." (*Traité de Chimie*, Paris, 1846, tome vi., p. 380.) This opinion of Dumas is based on experiments showing that fibrin is reduced to a jelly-like consistence by the action of six parts of hydrochloric acid with ten thousand parts of water, and is afterward completely dissolved by adding to the mixture a few drops of rennet.

[1] LONGET, *op. cit.*, p. 214.

tral phosphate of lime and adding acetic, phosphoric, or hydrochloric acid, in such quantity that it certainly existed in a free state, the digestive properties of the fluid were retained. These authors regard it as essential that the normal acid of the gastric juice should be thus capable of being replaced indifferently by other acids; for, they say, in case any salt were introduced into the stomach which would be decomposed by the lactic acid of the gastric juice, digestion would be interfered with, unless the liberated acid could take its place.[1] It can readily be appreciated that transient disturbances might occur from this cause were the existence of any one acid principle indispensable to the digestive properties of the gastric juice; while if only a certain degree of acidity were required, this condition might be produced by any acid, either derived from the food or produced by secretion.

Enough has already been said under the head of the organic principle of the gastric juice to show that the presence of this substance is likewise a condition indispensable to digestion.

The necessity of an acid and an organic principle in the gastric juice can be shown by the following simple experiment, which we have often made use of as a class-demonstration: Take three cubes of coagulated white of egg, one of which is put into pure gastric juice, the other into gastric juice which has been carefully neutralized, and the third into gastric juice in which the properties of the organic principle have been destroyed by boiling. If the three specimens be kept at about the temperature of the body for a number of hours, the albumen in the pure juice will be found to be partially or completely reduced to a grumous consistence, readily breaking up between the fingers, while the other specimens are scarcely acted upon.

As far as has been ascertained by experiments in artificial digestion, the mucus, which always exists in greater or less

[1] *Op. cit.—Comptes Rendus*, Paris, 1844, tome xix., p. 1289.

quantity in the stomach, does not seem to be important. It is usual in these experiments to separate mucus and extraneous matters from gastric juice by filtration before it is used; and the digestive properties of the fluid thus treated are not sensibly affected when the mucus is allowed to remain.[1]

In studying the physiological action of the gastric juice, it must always be borne in mind that the general process of digestion is accomplished by the combined, as well as the successive action of the different fluids. The act should be viewed in its *ensemble*, rather than as a process consisting of several successive and distinct operations, in which different classes of principles are dissolved by distinct fluids. The food meets with the gastric juice after having become impregnated with an immense quantity of saliva; and it passes from the stomach to be acted upon by the intestinal fluids, having imbibed both saliva and gastric juice. By studying the different digestive fluids in too exclusive a manner, many physiologists, while professing to assign definite and distinct properties to each, thus investing the function of digestion with an attraction of simplicity, have necessarily ignored or distorted facts, and assumed a completeness for the sum of our information on this subject, which does not exist. There could be no more serious barrier than this in the way of farther knowledge of a function, concerning which much remains to be learned.

When the acts which take place in the mouth are properly performed, the following alimentary substances, comminuted by the action of the teeth and thoroughly insalivated, are taken into the stomach: muscular tissue, containing the

[1] Blondlot has shown (*Traité Analytique de la Digestion*, Paris, 1843, p. 292), that mucus is not acted upon by the gastric juice, even after prolonged contact at the temperature of the body. The mucus which is secreted in the stomach is, as far as has been ascertained, precisely like the secretion of ordinary mucous membranes; and it does not possess any peculiar properties, like, for example, the viscid secretion from the intestinal mucous membrane.

muscular substance enveloped in its sarcolemma, blood-vessels, nerves, white fibrous tissue holding the muscular fibres together, interstitial fat, and a small quantity of albumen, fibrin, and corpuscles from the blood, all combined with a considerable quantity of inorganic saline matters; albumen, sometimes unchanged, but generally in a more or less perfectly coagulated condition; fatty matter, sometimes in the form of oil and sometimes enclosed in vesicles, constituting adipose tissue; gelatine and animal matters in a liquid form extracted from meats, as in soups; caseine, in its liquid form united with butter and salts in milk, and coagulated in connection with various other principles in cheese; vegetable nitrogenized principles, of which gluten may be taken as the type; vegetable fats and oils; saccharine principles, both from the animal and vegetable kingdom, but chiefly from the vegetable; the different varieties of amylaceous principles; and finally, organic acids and salts, chiefly from vegetables. These principles, particularly those from the vegetable kingdom, are united with more or less innutritious matter, such as cellulose. They are also seasoned with aromatic principles, condiments, etc., which are not directly used in nutrition.[1]

The various articles coming under the head of drinks are taken without any considerable admixture with the saliva. They embrace water, the various nutritious or stimulant infusions (including alcoholic beverages), with a small proportion of inorganic salts in solution.

All articles enumerated above are more or less modified in the stomach; and the action of the gastric juice upon them will now be taken up in detail.

Action of the Gastric Juice upon Meats.—There are three ways in which the action of the gastric juice upon the various articles of food may be studied. One is to subject them to the action of the pure fluid taken from the stomach, as

[1] Condiments and articles of this class have already been considered with sufficient minuteness. (See p. 100.)

was done by Beaumont in the human subject, and by Blondlot and others in experiments upon the inferior animals; another is to make use of properly prepared acidulated infusions of the mucous membrane of the stomach, which have been shown by Schwann, Müller, Mialhe, and others, to have sensibly the same properties as the gastric juice, differing only in activity; and another is to examine from time to time the contents of the stomach after food has been taken. By all of these methods of study, it has been shown that the digestion of meat in the stomach is far from being complete. The parts of the muscular tissue most easily attacked are the fibrous tissue which holds the muscular fibres together, with the sarcolemma, or sheath of the fibres themselves. If the gastric juice of the dog be placed in a vessel with finely chopped lean meat, and kept in contact with it for a number of hours at from 80° to 100° Fahr., agitating the vessel occasionally, so as to subject, as far as possible, every particle of the meat to its action, the filtered fluid will be found increased in density, its acidity diminished in intensity, and presenting all the evidences of having dissolved a considerable portion of the tissue. There always, however, will remain a certain portion which has not been dissolved. Its constitution is nevertheless materially changed; for it no longer possesses the ordinary character of muscular tissue, but easily breaks down between the fingers into a pultaceous mass. On subjecting this residue to microscopic examination, it is found not to contain any of the white inelastic fibres; and the fibres of muscular tissue, though presenting the well-marked and characteristic striæ, are broken into short pieces and possess very little tenacity. It is evidently only the muscular substance which remains; the connective tissue and the sarcolemma having been dissolved. These facts we have repeatedly noted, and even on adding fresh juice to the undigested matter, have been unable to dissolve it to any considerable extent; the residue not being sensibly diminished in quantity, and the muscular substance always

presenting its characteristic striæ, on microscopic examination.

Although it is stated by many, in a general way, that the nitrogenized alimentary principles are digested by the gastric juice, a review of actual experiments will show that the digestion of meat in the stomach is substantially such as we have just indicated. Beaumont, in his experiments on artificial digestion, while he frequently states that the meat is completely digested, describes the mixture, after a digestion of eight or nine hours, as about the color of whey, and depositing a fine sediment of a reddish color after standing for a few minutes.[1] In no case does he distinctly state that meat is ever completely dissolved. Pappenheim is quoted by Longet as having examined animal matters, especially muscular tissue, in various stages of digestion by the gastric juice, and noted the disintegration of the tissue and division of the muscular fibres into fragments, but not the solution of the true muscular substance.[2] Burdach, in his elaborate treatise on physiology, describes the digestion of meat as consisting in the solution of its cellular tissue, which is dissolved, first separating the muscular fibres, and finally being converted into a pultaceous mass, more or less brown.[3] The same facts, essentially, have been noted by Bernard in experiments with the gastric juice of different animals. This observer has found that the fluid from the stomach of the rabbit or the horse is much inferior, as regards the activity of its action upon meat, to the gastric juice of the dog.[4] He compares the disintegrating process which takes place in the stomach to the action of boiling water in cooking. Dr. Dalton has found, in the dog, that during digestion, partially disintegrated muscular fibres, still recognizable on microscopic examination,

[1] Beaumont, *Experiments and Observations on the Gastric Juice and the Physiology of Digestion*, Plattsburg, 1833, p. 129.

[2] Longet, *op. cit.*, tome i., p. 222.

[3] Burdach, *Traité de Physiologie*, Paris, 1841, tome ix., p. 273.

[4] Bernard, *Leçons de Physiologie Expérimentale*, Paris, 1851, p. 414.

pass from the stomach into the small intestine, and can be distinguished in the tube for a considerable distance.[1]

Whether the gastric juice be entirely incapable of acting upon the muscular substance or not, the above-mentioned facts clearly show that, usually, muscular tissue is not completely digested in the stomach. The action in this organ is to dissolve out the inter-muscular fibrous tissue and the sarcolemma, or sheath of the muscular fibres, setting the true muscular substance free, and breaking it up into small particles. The mass of tissue is thus reduced to the condition of a thin pultaceous fluid which passes into the small intestine, where the process of digestion is completed. As far as a great part of the muscular substance is concerned, the action in the stomach is preparatory, and not final.

The constituents of the blood (fibrin, albumen, and corpuscles), which may be introduced in small quantity in connection with muscular tissue, are probably completely dissolved in the stomach.

Action upon Albumen, Fibrin, Caseine, and Gelatine.—Dr. Beaumont thought that raw albumen, or white of egg, became first coagulated in the stomach, and was afterward dissolved; but this has been disproved by numerous other observers, who, however, have experimented chiefly on dogs. Reference to the experiments of Beaumont will show that the phenomena which he described as taking place in a mixture of equal parts of white of egg and gastric juice, kept at the temperature of the body for three hours, do not really indicate coagulation. He states that "in ten or fifteen minutes, small, white flocculi began to appear, floating about; and the mixture became of an opaque and whitish appearance. This continued slowly and uniformly to increase for three hours, at which time the fluid had become of a milky appearance; the small flocculi, or loose coagula,

[1] DALTON, *A Treatise on Human Physiology*, Philadelphia, 1864, p. 157 *et seq.*

had mostly disappeared, and a light-colored sediment subsided to the bottom."[1] If white of egg be mixed with equal parts of pure water and be gently stirred with a glass rod, the same small white flocculi will make their appearance, and the mixture will become opaque and whitish. This is due to the disengagement of shreds of the membranes in which the clear albumen is contained; these being invisible in pure white of egg, from the fact that the two substances have the same refractive power. A very different appearance is presented when water containing even a small quantity of nitric acid is added to the albumen. True coagulation then takes place; and the mixture becomes immediately filled with large dense clots; or the mass may become nearly solidified, if the acid be added in sufficient quantity. Longet and Schiff injected a filtered watery mixture of albumen into the stomach of the dog through a fistulous opening, and found that no coagulation took place.[2]

The action of the gastric juice upon uncooked white of egg is to disintegrate its structure, separating, and finally dissolving the membranous sacs in which the pure albumen is contained. It also acts upon the albumen itself, forming a new fluid substance, called albuminose, or albumen-peptone, which, unlike albumen, is not coagulated by heat or acids, but is precipitated by alcohol, tannin, and many of the metallic salts.

The digestion of raw, or imperfectly coagulated albumen, takes place with considerable rapidity in the stomach. Beaumont gave St. Martin the white of two eggs when the stomach was empty, and found that it had been completely disposed of in an hour and a half.[3] The digestion of albumen in this form is more rapid than when it has been completely coagulated by heat.

Coagulated white of egg is almost, if not entirely dissolved by the gastric juice. If a cube of albumen in this con-

[1] BEAUMONT, *op. cit.*, p. 148.

[2] LONGET, *op. cit.*, p. 220.

[3] *Op. cit.*, p. 149.

dition be subjected to the action of the gastric juice at the temperature of the body, taking care to agitate it occasionally, the edges and corners gradually become rounded, and nearly the whole mass finally breaks down and is dissolved, having previously become softened, so that it is easily crushed between the fingers. Usually, one or two points appear in the mass, which are acted upon with difficulty or may resist solution entirely. It is a matter of common, as well as scientific observation, that hard-boiled eggs are less easily digested than when they are soft-boiled or raw.

The products of the digestion of raw and of coagulated albumen (albumen-peptone) are essentially the same. It is probable that the entire process of digestion and absorption of albumen takes place in the stomach; and if any pass out at the pylorus, the quantity is exceedingly small.

Fibrin, as distinguished from the so-called fibrin of the muscular tissue, or musculine, is not a very important article of diet. The action of the gastric juice upon it is more rapid and complete than upon albumen. Mialhe, who has made numerous experiments on the action of the gastric juice upon albuminoid substances, found the coagulated and washed fibrin of the blood readily fluidified by an acidulated solution of pepsin.[1] The well known action upon fibrin of water slightly acidulated with hydrochloric acid has led some physiologists to assume that the acid is the only principle in the gastric juice necessary to the digestion of this principle;[2] but careful observations on the comparative action of acidulated water and of artificial or natural gastric juice show that

[1] MIALHE, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 115 *et seq.*

[2] BOUCHARDAT ET SANDRAS, *Recherches sur la Digestion.—Annales de Chimie et de Physique*, Paris, 1842, 3me serie, tome v., p. 478 *et seq.* These observers attached great importance to the acid principle of the gastric juice in digestion. They supposed that it was the sole principle necessary to the digestion of fibrin and some other nitrogenized substances, though they recognized the necessity of the organic substance in the digestion of coagulated albumen.

the presence of the organic principle is necessary to the digestion of this, as well as other nitrogenized alimentary principles. The action of water containing a small proportion of acid is to render fibrin soft and transparent, frequently giving to the entire liquid a jelly-like consistence. The substance thus produced has been likened by Mialhe to caseine, as it is precipitable by acids and by rennet. The result of the digestion of fibrin in the gastric juice, or in an acidulated fluid to which pepsin has been added, is its complete solution and transformation into a substance which is not affected by heat, acids, or by rennet.

The substance resulting from the action of gastric juice upon fibrin, called by Lehmann, fibrin-peptone, presents many points of similarity with the albumen-peptone, but nevertheless has certain distinctive characters. Lehmann, indeed, supposes that there are differences between the products of the digestion of all the various nitrogenized alimentary principles, sufficiently well marked to distinguish them from each other.[1]

Liquid caseine is immediately coagulated by the gastric juice, by virtue both of the free acid and the organic matter. Rennet, which is so largely used for the coagulation of caseine in the manufacture of cheese, is probably nearly identical with pepsin. Once coagulated, caseine is acted upon in the same way as coagulated albumen. The caseine which is taken as an ingredient of cheese is digested in the same way. According to Lehmann, coagulated caseine requires a longer time for its solution in the stomach than most other nitrogenized substances; and it is stated by the same author, on the authority of Elsässer, that the caseine of human milk, which coagulates only into a sort of jelly, is more easily digested than caseine from cow's milk.[2]

The product of the digestion of caseine is a soluble sub-

[1] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 451 *et seq*
[2] Ibid.

stance, not coagulable by heat or the acids, called by Lehmann, caseine-peptone.

Gelatine is rapidly dissolved in the gastric juice, when it loses the characters by which it is ordinarily recognized, and no longer forms a jelly on cooling.[1] This substance is much more rapidly disposed of than the tissues from which it is formed; and the products of its digestion in the gastric juice resemble the substances resulting from the digestion of the albuminoids generally.

Action on Vegetable Nitrogenized Principles.—These principles, of which gluten may be taken as the type, are undoubtedly chiefly, if not entirely, digested in the stomach. Raw gluten is acted upon very much in the same way as fibrin; and cooked gluten behaves like coagulated albumen. Vegetable articles of food generally contain gluten in greater or less quantity, or principles resembling it, as well as various non-nitrogenized principles, and cellulose. The fact that these articles are not easily attacked in any portion of the alimentary canal, unless they have been well comminuted in the mouth, is shown by the passage of grains of corn, beans, etc., in the fæces. When properly prepared by mastication and insalivation, the action of the gastric juice is to disintegrate them, dissolving out the nitrogenized principles, freeing the starch and other matters so that they may be more easily acted upon in the intestines, and leaving the hard indigest-

[1] Blondlot studied the comparative action of acidulated water and gastric juice from the dog upon gelatine. He took three vessels, each capable of holding thirty grammes, in each of which he put ten grammes of jelly obtained by boiling one part of isinglass with twenty of water. He then filled the vessels, one with gastric juice, and the two others with water acidulated with phosphoric and with acetic acid. By the action of heat, the jelly was soon dissolved in each of the three vessels. After ten hours, he found that while the specimens of gelatine in the acidulated water formed a jelly on cooling, so that the vessel could be inverted without any of the substances escaping, the specimen which had been digested in gastric juice retained its fluidity. (*Traité Analytique de la Digestion*, Paris, 1843, p. 290.)

ible matters, such as cellulose, to pass away in the fæces. The nitrogenized portions of bread are probably acted upon in the stomach in the same way and to the same extent as albumen, fibrin, and caseine.

Albuminose, or Peptones.

The product, or the sum of the products of the digestion of nitrogenized alimentary principles in the stomach, was first closely studied by Mialhe, who regarded the action of the gastric juice on all principles of this class as resulting in their transformation into a new substance which he called albuminose.[1] Lehmann has since investigated the principles resulting from the action of the gastric juice on various nitrogenized matters, and describes them under the name of peptones.[2] It has been conclusively shown that stomach-digestion is not merely a solution of certain alimentary principles, but that these substances undergo very marked changes, and lose the properties by which they are generally recognized. That the different principles resulting from this transformation resemble each other very closely is also undoubted; but there must be, as is suggested by Mialhe, differences in the chemical composition of the products of digestion of different principles, as well as differences, which have lately been noted, with regard to their behavior with reagents.

The albuminose described by Mialhe is a colorless liquid, with a feeble odor resembling that of meat. It is not coagulable by heat, acids, or by pepsin; a property which distinguishes it from almost all of the nitrogenized principles of food. It is coagulated, however, by many of the metallic salts, by chlorine, and by a solution of tannin after it has been acidulated by nitric acid.[3] An interesting peculiarity of this prin-

[1] MIALHE, *L'Union Médicale*, Paris, septembre, 1847, and *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 124 *et seq.*

[2] *Op. cit.*, vol. i., p. 451.

[3] MIALHE, *op. cit.*, p. 125.

ciple is its curious modifying influence upon Trommer's test for sugar. Prof. Dalton first noted a peculiar interference with this test in gastric juice taken from a fistula in a dog. He found that a drop of honey mixed with a drachm or two of gastric juice presented, on the addition of sulphate of copper and a solution of potash, the following appearance: On adding one or two drops of the solution of copper, the ordinary faint blue tint was produced; but on adding the potash, instead of this producing a greater intensity in the blue color, as is usually the case, the solution became of a rich purple tinge, which changed to a yellow on boiling, without any deposit of the suboxide of copper. This peculiarity was found by Dalton to be due neither to the free acid of the gastric juice nor to the organic matter; for it was present, both in gastric juice which had been neutralized, and after the organic matter had been separated by boiling and filtration.[1] A year later, the same fact was noted by Longet, who ascertained that the peculiarity in the reaction was due to the presence of albuminose, and assumed to be able to distinguish in this way between albuminoid substances and the principles resulting from their digestion in the stomach;[2] an explanation which was afterward adopted by Dalton.[3] In the experiments of Dalton, the secretion of gastric juice was generally excited by feeding the animal with small firm pieces of meat, the exterior having been hardened by boiling water; and obtained in this way, the filtered fluid from the stomach, even that which flows immediately after the introduction of the meat, generally contains a small quantity of albuminose.

Mialhe found, on evaporating albuminose to dryness, that

[1] DALTON, *On the Gastric Juice and its Office in Digestion.—American Journal of the Medical Sciences*, October, 1854, p. 319.

[2] LONGET, *Nouvelles Recherches relatives à l'Action du Suc Gastrique sur les Matières Albuminoïdes.—Gazette Hebdomadaire*, No. 6, Paris, février, 1855, tome ii., p. 103.

[3] DALTON, *A Treatise on Human Physiology*, third edition, Philadelphia, 1864, p. 143.

the residue consisted of a yellowish-white substance, resembling desiccated white of egg. The dry residue is soluble in water, when it regains its characteristic properties; but it is entirely insoluble in alcohol.

The observations of Lehmann on albuminose, or peptones, were more extended. He found a great similarity between the substances resulting from the digestion of the various albuminoid bodies, and even those produced by the digestion of gluten, chondrine, and gelatinous tissues. He was unable to obtain the peptones free from mineral substances. In the condition of greatest purity in which they have been obtained, they have been found to be white amorphous bodies, odorless, having a mucous taste, very soluble in water, and insoluble in alcohol. Their watery solutions redden litmus. They combine readily with bases, forming neutral salts which are soluble in water.[1] The differences between the various peptones are not, as yet, very well defined. Lehmann states that they always contain the same proportion of sulphur that existed in the albuminoid substance from which they are formed.

According to Lehmann, the gastric juice transforms the various nitrogenized alimentary principles into these liquid substances, which are not easily coagulable, and which present slight differences in chemical composition and general properties, varying with the principles from which they are formed. Those which have been most particularly described are fibrin-peptone, albumen-peptone, and caseine-peptone. It does not appear, however, that the differences between the substances resulting from the digestion of the various nitrogenized bodies are sufficiently definite to establish a rigorous distinction between them; and until we are better acquainted with their distinctive properties, it is best, perhaps, to preserve the name albuminose, applying it to the substance resulting from the action of the gastric juice upon the albuminoids. We are as yet too little acquainted

[1] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 451.

with the chemistry of organic nitrogenized bodies to be able to follow out closely all the changes which take place during their digestion.[1]

With even the imperfect knowledge which we have of the properties of albuminose, it is evident that the object of stomach-digestion, aside from its function in preparing certain articles for the action of the intestinal fluids, is not simply to liquefy certain of the alimentary principles, but to change them in such a way as to render them endosmotic and provide against the coagulation which is so readily induced in ordinary nitrogenized bodies. Albuminose passes through membranes with great facility, and, as we have seen, is not coagulable by heat or the acids.

Another, the most important and the essential change which is exerted by the gastric juice upon the albuminoids, is that by which they are rendered capable of assimilation by the system after their absorption. The important fact that pure albumen and gelatine, when injected into the blood, are not assimilable but are rejected by the kidneys was first demonstrated by Bernard and Bärreswil. These observers found also that albumen and gelatine which had previously been digested in gastric juice were assimilated in the same way as though they had penetrated by the natural process of absorption from the alimentary canal.[2] Mialhe has repeated these experiments, and arrived at the same conclusions. He has also found that the same is true of caseine and fibrin.[3]

[1] Before the researches of Mialhe, little or nothing of a positive nature was known regarding the products of stomach-digestion. The substance now called albuminose was then indefinitely described under the names of osmazome, salivary matter, gelatiniform matter, etc.

[2] BERNARD ET BARRESWIL, *Mémoire sur le Suc Gastrique et son Rôle dans la Nutrition.—Comptes Rendus*, Paris, 1844, 2me série, tome xii., p. 277.

[3] MIALHE, *op. cit.*, p. 127. With regard to the experiments of Bernard and Barreswil, it is justly remarked by Bérard (*Traité de Physiologie*, tome ii., p. 133) that, as the digestion of albuminoid principles takes away from them the characters by which they are ordinarily recognized, albumen could not, of course, be

These facts, showing that something more is necessary in stomach-digestion than mere solution, point to pepsin as the important active principle in producing the peculiar modifications so necessary to proper assimilation of nitrogenized alimentary substances. The action which takes place is one of those ordinarily termed catalytic, in which the pepsin, acting by its mere presence, as a ferment, induces these peculiar changes.[1] They are, however, an essential, and the most important part of the action of the gastric juice, and the transformation into albuminose takes place in all nitrogenized principles which are liquefied in the stomach. As it is impossible for two catalytic processes to take place at the same time in any single organic substance, the more powerful always overcoming and taking the place of the weaker, it is evident that when nitrogenized principles in process of putrefaction are introduced into the stomach, the catalytic process of putrefaction must cease when the changes which take place in digestion become established. This explains the antiseptic properties of the gastric juice, and the frequent innocuousness of animal substances in various stages of decomposition taken into the stomach.

Action of the Gastric Juice on Fats.—Beaumont does not say much with regard to the changes which fatty substances undergo in the stomach, except that they "are digested with great difficulty."[2] All the recent observations on this subject show that these principles, when taken in the condition of oil, pass out at the pylorus unchanged. Most

recognized in the urine. In a subsequent account by Bernard of experiments on the injection of albumen into the circulation (*Liquides de l'Organisme*, Paris, 1859, tome ii., p. 459), there is no mention of the effects of injecting albumen dissolved in the gastric juice, though the first experiments upon the injection of pure albumen are confirmed. The facts are nevertheless interesting and instructive, as showing the want of assimilation of undigested nitrogenized principles mixed with the blood.

[1] For a definition of the process of catalysis, see vol. i., p. 74.

[2] *Op. cit.*, p. 45.

of the fatty constituents of the food are liquefied at the temperature of the body; and when taken in the form of adipose tissue, the little vesicles in which the oleaginous matter is contained are dissolved, the fat is set free and melted, and floats in the form of great drops of oil on the alimentary mass. The action of the stomach, then, seems to be to prepare the fats, chiefly by dissolving the adipose vesicles, for the complete digestion which takes place in the small intestine.

Action on Saccharine and Amylaceous Principles.—The varieties of sugar of which glucose is the type undergo little, if any, change in digestion, and are probably for the most part directly absorbed by the mucous membrane of the stomach. This is not the case, however, with the varieties of sugar classed with cane-sugar. The experiments of Bernard and Barreswil[1] have shown that cane-sugar injected into the veins of a living animal is not assimilated by the system, but is immediately rejected by the kidneys. When, however, it has been changed into glucose by the action of a dilute acid, or by digestion in the gastric juice, it no longer behaves as a foreign substance, and does not appear in the urine.

This leads to a consideration of the changes which cane-sugar undergoes in the stomach. Experiments have shown that this variety of sugar, after being digested for several hours in the gastric juice, is slowly converted into glucose. This action, according to the recent observations of Longet and Schiff, does not depend upon any constituent of the gastric juice except the free acid; and they found that an exceedingly dilute mixture of hydrochloric acid had an equally marked effect.[2] Dalton found that, in the dog, the ingestion of cane-sugar induced, almost invariably, an immediate reflux of intestinal fluids, including bile, by which it was promptly

[1] *Loc. cit.*

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 221.

converted into glucose.[1] This, however, he found to be only temporary; and in experiments in which half an ounce of loaf-sugar was given to the animal after a twelve hours' fast, unaltered cane-sugar remained in the stomach for from two and a half to three hours.

Experiments in artificial digestion have shown that cane-sugar is transformed into glucose by the gastric juice very slowly, the action of this fluid in no way differing from that of very dilute acids. In the natural process of digestion, this action may take place to a certain extent; but it is not shown to be constant or important, and we must look to intestinal digestion for rapid and effective transformation of cane-sugar.

The action of gastric juice, unmixed with saliva, upon starch is entirely negative, as far as any transformation into sugar is concerned. When the starch is enclosed in vegetable cells, it is set free by the action of the gastric juice upon the nitrogenized parts. It has been found by Bernard that raw starch, in the form of granules, becomes hydrated in the stomach; and he attributes this action to the elevated temperature and to the acidity of the contents of the organ.[2] This is not the form, however, in which starch is generally taken by the human subject; but when it is so taken, the stomach evidently assists in preparing it for the more complete processes of digestion which are to take place in the small intestine.

Cooked or hydrated starch, the form in which it exists in bread, farinaceous preparations generally, and ordinary vegetables, is not affected by the pure gastric juice, and passes out at the pylorus unchanged. It must be remembered, however, that the gastric juice does not prevent a continuance of the action induced by the saliva; and experiments have shown that gastric juice taken from the stomach, when it contains a notable quantity of saliva, has, to a certain extent, the power

[1] DALTON, *On the Gastric Juice and its Office in Digestion.—American Journal of the Medical Sciences*, October, 1854, p. 319.

[2] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 401.

of transforming starch into sugar.[1] It has already been remarked that, with regard to this question, experiments on dogs, as these animals do not naturally take starch as food, do not correspond with observations on the human subject.

The changes which vegetable acids and salts, the various inorganic constituents of food, and the liquids which come under the head of drinks undergo in the stomach are very slight. Most of these principles can hardly be said to be digested; for they are either liquid or in solution in water, and are capable of direct absorption and assimilation. With regard to most of the inorganic salts, they either exist in small quantity in the ordinary water taken as drink, or are united with organic nitrogenized principles. In the latter case, they become intimately combined with the organic principles resulting from stomach-digestion. We have already seen that the various peptones have been found to contain the same inorganic constituents which existed in the nitrogenized principles from which they were formed.

Some discussion has arisen with regard to the action of the fluids of the stomach upon the phosphate and the carbonate of lime; salts which are considered nearly, if not entirely, insoluble. The action upon these principles is interesting, as they are essential constituents of the osseous tissues. Observations in both natural and artificial digestion have shown that the calcareous constituents of bone are, to a certain extent, dissolved in the gastric juice. The experiments of Chossat upon animals deprived of these principles in the food demonstrated that they are absolutely necessary to proper nutrition,[2] and therefore must be dissolved somewhere in the alimentary canal· and the well-known fact that the phosphate of lime is soluble in acid fluids, when it is converted into the biphosphate, would point at once to the gastric juice as the agent for its digestion. In fact, it has been clearly shown that bones are digested to a considerable extent in the stom-

[1] See page 177. [2] See page 65.

ach, though the greater part passes through the alimentary canal and is discharged unchanged in the fæces. Beaumont has shown this to be true in the human subject by experiments which he performed, out of the body, with gastric juice taken from St. Martin.[1] In these observations, after a certain portion of the bone had been dissolved, the action was increased by the addition of fresh gastric juice. In the natural process of digestion, the solution of the calcareous elements of bone is more rapid than in artificial digestion, from the fact that the juice is being continually absorbed and secreted anew by the mucous membrane of the stomach.

Duration of Stomach-Digestion.

Now that the relative importance of the stomach and the small intestines in digestion is more fully understood, less interest is attached to the length of time required for the action of the gastric juice upon different articles of food than formerly, when the stomach was regarded as the principal, if not the sole digestive organ. It was thought at one time that the food was converted in the stomach into a pultaceous mass called chyme,[2] which passed into the intestine, where the assimilable portion (the chyle) was separated and absorbed by the lacteals. Beaumont, in preparing the elaborate table which has been so much quoted, conceived that the simple action of the gastric juice represented the chief part of the digestive process; and that it was possible, from experiments with this fluid, to ascertain the digestibility of different articles. From this point of view he regards fatty substances, which are now known to be digested

[1] BEAUMONT, *op. cit.*, p. 200.

[2] The word chyme, like many words used by the earlier physiologists, under the supposition that they represented definite principles, has for some time been practically discarded, on account of its indefinite signification. It is particularly inexact, as the mass resulting from the action of the gastric juice upon the varied articles used as food is composed of many undigested substances, as well as distinct substances resulting from the digestion of different alimentary principles.

exclusively in the small intestines, as requiring a very long time for their digestion.

Understanding, as we do, that comparatively few articles, and these belonging exclusively to the class of organic nitrogenized principles, are completely dissolved in the stomach, it is evident that the length of time during which food remains in this organ, or the time occupied in the solution of food by gastric juice, out of the body, does not represent the absolute digestibility of different articles. It is, nevertheless, an interesting and important question to ascertain, as nearly as possible, the duration of stomach-digestion.

There has certainly never been presented so favorable an opportunity for determining the duration of stomach-digestion as in the case of St. Martin. From a very great number of observations made on digestion in the stomach itself, Beaumont came to the conclusion that "the time ordinarily required for the disposal of a moderate meal of the fibrous parts of meat, with bread, etc., is three to three and a half hours."[1] The observations of Prof. F. G. Smith, made upon St. Martin, many years later, give two hours as the longest time that aliments remained in the stomach.[2] In a remarkable case of intestinal fistula, reported by Prof. Busch, of Bonn, it was noted that food began to pass out of the stomach into the intestines fifteen minutes after its ingestion, and continued to pass for three or four hours, until the stomach was emptied.[3]

Undoubtedly the duration of stomach-digestion varies in different individuals, and is greatly dependent upon the kind and quantity of food taken, conditions of the nervous system, exercise, etc. As a mere approximation, the average

[1] *Op. cit.*, p. 275.

[2] F. G. Smith, *Expériences sur la Digestion.—Journal de la Physiologie*, Paris, 1858, tome i., p. 146, and *Philadelphia Medical Examiner*, July and September, 1856.

[3] Busch, *Beitrag zur Physiologie der Verdauungsorgane.*—Virchow's *Archiv*, Berlin, 1858, Bd. xiv., S. 140, *et seq.*; and, *American Journal of the Medical Sciences*, Philadelphia, July, 1860, p. 219.

time that food remains in the stomach after an ordinary meal may be stated to be from two to four hours.

Digestibility of Different Aliments in the Stomach.—We are indebted to Beaumont for nearly all that is positively known regarding the facility with which different articles are disposed of in the stomach. While it is fully understood that most of the substances experimented upon by him are not completely digested by the gastric juice, and although he was often wrong in assuming that articles of food were digested when they had not become completely liquefied and consequently endosmotic, the table which he prepared with so much care was the result of such conscientious and extended research, that it must always be recognized as of great value. Nearly all of the results given in the table are derived from experiments frequently repeated, and "performed under the naturally healthy condition of the stomach and ordinary exercise." They show the mean time employed in the digestion, in the stomach, of most of the ordinary articles of food, in the person of a healthy young man of good digestive powers. Of course it must be understood that there are important peculiarities in different individuals, which could not be considered. As many of the alimentary substances experimented upon are but slightly acted on by the gastric juice, it has been thought proper, in making the selections from the table, to discard all articles which are mainly digested in the small intestine.

With these modifications, therefore, the following table may be taken as representing the comparative rapidity with which most of the ordinary nitrogenized articles are acted upon in the stomach; they being either completely dissolved, and probably directly absorbed by its mucous membrane or prepared for the action of the intestinal fluids, passing gradually out at the pylorus. It must be remembered, however, that slow digestion does not always indicate that the process is difficult, and the action of the gastric fluids upon

many articles which apparently give no trouble in digestion is by no means rapid:

Table showing the Digestibility of various Alimentary Substances in the Stomach.[1]

Articles of Diet.	Mode of Preparation.	Hours, Min.	Articles of Diet.	Mode of Preparation.	Hours, Min.
Milk	Boiled	2·00	Chicken, full grown	Fricasseed	2·45
do.	Raw	2·15	Fowls, domestic	Boiled	4·00
Eggs, fresh	do.	2·00	do. do.	Roasted	4·00
do. do.	Whipped	1·30	Ducks, domesticated	do.	4·00
do. do.	Roasted	2·15	do. wild	do.	4·30
do. do.	Soft-boiled	3·00	Soup, barley	Boiled	1·30
do. do.	Hard-boiled	3·30	do. bean	do.	3·00
do. do.	Fried	3·30	do. chicken	do.	3 00
Custard	Baked	2·45	do. mutton	do.	3·30
Codfish, cured dry	Boiled	2·00	do. oyster	do.	3·30
Trout, salmon, fresh	do.	1·30	do. beef, vegetables and bread	do.	4·00
do. do. do.	Fried	1·30			
Bass, striped, do.	Broiled	3·00	do. marrow-bones	do.	4·15
Flounder, do.	Fried	3·30	Pigs' feet, soused	do.	1·00
Catfish, do.	do.	3·30	Tripe do.	do.	1·00
Salmon, salted	Boiled	4·00	Brains, animal	do.	1·45
Oysters, fresh	Raw	2·55	Spinal marrow, animal	do.	2·40
do. do.	Roasted	3·15	Liver, beeves', fresh	Broiled	2·00
do. do.	Stewed	3·30	Apeneurosis	Boiled	3·00
Venison steak	Broiled	1·35	Heart, animal	Fried	4·00
Pig, sucking	Roasted	2·30	Cartilage	Boiled	4·15
Lamb, fresh	Broiled	2·30	Tendon	do.	5·30
Beef, fresh, lean, rare	Roasted	3·00	Hash, meat, and vegetables.	Warmed	2·30
Beef-steak	Broiled	3·00	Sausage, fresh	Broiled	3·20
Beef, fresh, lean, dry	Roasted	3·30	Gelatine	Boiled	2·30
do. with mustard, etc.	Boiled	3·10	Cheese, old, strong	Raw	3·30
do. with salt only	do.	3·36	Green corn and beans	Boiled	3·45
do.	Fried	4·00	Beans, pod	do.	2·30
Mutton, fresh	Broiled	3·00	Parsnips	do.	2·30
do. do.	Boiled	3·00	Potatoes, Irish	Roasted	2·30
do. do.	Roasted	3·15	do. do.	Baked	2·30
Veal, fresh	Broiled	4·00	do. do.	Boiled	3·30
do. do.	Fried	4·30	Cabbage, head	Raw	2·30
Pork, steak	Broiled	3·15	do. do. with vinegar.	do.	2·00
do. fat and lean.	Roasted	5·15	do. do.	Boiled	4·30
do. recently salted	Raw	3·00	Carrot, orange	do.	3·15
do. do.	Stewed	3·00	Turnips, flat	do.	3·30
do. do.	Broiled	3·15	Beets	do.	3·45
do. do.	Fried	4·15	Bread, corn	Baked	3·15
do. do.	Boiled	4·30	do. wheat, fresh	do.	3·30
Turkey, wild	Roasted	2·18	Apples, sweet, mellow	Raw	1·30
do. domesticated	Boiled	2·25	do. sour, do.	do.	2·00
do. do.	Roasted	2·30	do. do. hard	do.	2·50
Goose, wild	do.	2·30			

Most of the facts recorded in the above table are in accordance with the popular ideas regarding the digestibility of various articles, based on general experience. With these

[1] In the original table given by Beaumont (*op. cit.*, p. 269 *et seq.*), there is also given the mean time of digestion artificially, in vials, on a bath. This has been omitted, as it often bears little relation to the time occupied in the digestion of the same principles in the stomach, and the results are of necessity quite inaccurate.

as a guide, the following may be taken as a summary of what is known regarding the facility with which different articles are disposed of in the stomach:

Milk is one of the articles digested in the stomach with greatest ease. Its highly nutritive properties and the variety of principles which it contains make it extremely valuable as an article of diet, particularly when the digestive powers are impaired, and when it is important to supply the system with considerable nutriment. Eggs are likewise highly nutritious and are easily digested. Raw and soft-boiled eggs are more easily digested than hard-boiled. Whipped eggs are apparently disposed of with great facility. As a rule, the flesh of fish is more easily digested than that of the warm-blooded animals. Oysters, especially when raw, are quite easy of digestion. The flesh of mammals seems to be more easily digested than the flesh of birds. Of the different kinds of meat, venison, lamb, beef, and mutton are easily digested, while veal and fat roast-pork are digested with difficulty. Soups are generally very easily digested. The animal substances which were found to be digested most rapidly, however, were tripe, pigs' feet, and brains. Vegetable articles are represented in the table as being digested in about the same time as ordinary animal food; but a great part of the digestion of these substances takes place in the small intestine. Bread is digested in about the time required for the digestion of the ordinary meats.

Action of the Gastric Juice upon the Coats of the Stomach.

Early in the physiological history of digestion, it was asked of those who adopted the view that the stomach secreted a fluid capable of dissolving many of the articles of food, why, if such a powerfully solvent fluid be thus secreted, are not the coats of the stomach dissolved and digested during life? This question was difficult to answer, even after the existence of a solvent gastric juice had been fully demonstrated. That the coats of the living stomach enjoy an im-

munity from the action of their own secretion during life is sufficiently evident; at the same time that it is apparent that tissues like the stomach, and even the stomach of animals bearing a close physiological resemblance to the human subject, as, for example, tripe, are easily disposed of when used as food.

Since the observations of Hunter, in 1772, in which it was shown that the stomach could be digested after death in persons killed suddenly when the organ contained an abundance of gastric juice, the cause of the immunity of the stomach from digestion during life has been much discussed. At the time of Hunter's observations, it was still a question among physiologists concerning the existence of a solvent fluid in the stomach; and the fact noted by him, that there were few dead bodies in which the great pouch was not in some degree digested, while in several subjects, killed suddenly while in good health and full digestion, parts of the cardiac portion, and sometimes even portions of the diaphragm were entirely dissolved, was a conclusive proof of the active solvent properties of the gastric juice.[1] The facts thus observed by Hunter, which belong more to pathology than to physiology, were confirmed by numerous physiologists; and it only remained to demonstrate the reason why solution of the coats of the stomach never took place during life.[2]

The explanation offered by Hunter himself has not been by all regarded as entirely satisfactory. It was assumed by

[1] JOHN HUNTER, *Observations on Certain Parts of the Animal Œconomy*, second edition, London, 1792, p. 226, and American edition of Works, Philadelphia, 1840, vol. ii., p. 144. The original paper was read before the *Royal Society*, June 18, 1772, and was printed in the *Philosophical Transactions*, vol. lxii.

[2] It has been found that when the human subject or one of the inferior animals is killed while in full digestion, the stomach will be digested and generally perforated after death, the action taking place in the most dependent portion. In order to secure this effect, it is only necessary to maintain the natural temperature of the body; this being a condition indispensable to the action of the gastric juice, under any circumstances. We have already alluded (p. 230) to the researches of Mr. T. W. King on this subject, in connection with the function of different parts of the mucous membrane of the stomach.

him that "animals, or parts of animals, possessed of the living principle, when taken into the stomach, are not in the least affected by the powers of that viscus, so long as the animal principle remains."[1] It was also assumed that, by virtue of this principle, many animals are capable of inhabiting the stomach, living and even breeding there. It is undoubtedly true that a living, highly organized part, abundantly supplied with blood-vessels, the process of destructive assimilation and nutrition taking place in its substance with great activity, is protected from the action of a fluid like the gastric juice by the very conditions of its existence; but it is desirable, if possible, to define these protecting conditions a little more closely. It is important, moreover, to know whether it is literally true that animals may maintain an independent existence in the living stomach, as was supposed by Hunter. A recent writer on this subject states that there are no examples of this to be found.[2] The parasites which infest the stomachs of some of the inferior animals, as the horse or sheep, are firmly attached to, and, indeed, partly buried in the mucous membrane. In investigating the accuracy of a popular belief that lizards and various other animals of that class frequently exist for a long time in the human stomach, Dr. Dalton has lately shown that the ordinary garden-slug and lizards, introduced living into the stomach of the dog, are soon killed and are easily digested.[3] An interesting experiment by Bernard has shown most conclusively that the nutritive processes, as they take place in cold-blooded animals, do not enable the tissues to resist the action of the gastric juice. He introduced through a fistulous opening into the stomach of a dog the posterior extremities

[1] Hunter, *Observations on Certain Parts of the Animal Œconomy*, London, 1792, p. 228.

[2] Pavy, *On the Immunity enjoyed by the Stomach from being digested by its own Secretion during Life.—Philosophical Transactions*, London, 1863, p. 169.

[3] Dalton, *Experimental Investigations to determine whether the Garden-Slug can live in the Human Stomach.—American Journal of the Medical Sciences*, April, 1865, p. 334 *et seq.*

of a living frog, and the parts were sensibly acted upon by the gastric juice, even while the animal was alive and active.[1] A still more striking experiment was made by Dr. F. W. Pavy, who introduced through a fistulous opening into the stomach of a dog in full digestion, one of the ears of a rabbit, taking care to avoid mechanical injury, and obstructing the circulation in the part as little as possible. At the end of two hours, several large spots of erosion were observed upon the ear; and at the end of four and a half hours, rather more than half an inch of the tip had been removed, "a small fragment only being left attached by a narrow shred to the remainder of the ear."[2]

Bernard denies the protective influence of the "living principle," as advanced by Hunter, and attributes the immunity of the stomach from digestion during life to the presence of a coating of mucus and epithelium, the latter being continually dissolved by the gastric juice, but renewed as fast as it is destroyed. According to this supposition, as soon as life ceases, the epithelium being no longer renewed, the coats of the stomach are attacked, if any gastric juice exist in its cavity. The finger, when introduced into the living stomach through a fistula, is not acted upon, because its epidermic covering is not capable of being dissolved by the gastric juice; and the legs of the living frog are digested because the epithelium is not readily restored after it is removed.[3] This explanation is unsatisfactory, for several reasons. In the first place, it is simply a gratuitous supposition that the epithelium of the stomach is constantly destroyed by the gastric juice, and is as constantly reproduced. Again, in cases of ulceration of the stomach, or other structural diseases in which portions of the mucous membrane are deprived of epithelium, the parts thus denuded are not acted upon by the gastric juice during life; and furthermore, Pavy has shown by experi-

[1] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 408.
PAVY, *op. cit.*, p. 162.
[3] BERNARD, *op. cit.*, p. 404 *et seq.*

ment that the mucous membrane may be dissected from a portion of the stomach of a living animal, and the organ returned to its place, and yet secretion of gastric juice and digestion of food take place as usual, without the denuded portion being acted upon.[1]

An explanation recently offered by Pavy is exceedingly ingenious; and the experiments by which it is supported demonstrate one of the conditions of highly organized living parts which is inconsistent with the digestive action of the gastric juice. It is well known that acidity is a condition indispensable to the action of the gastric juice upon any principle or tissue; and so long as the mucous membrane lining the stomach is abundantly supplied with a constantly changing current of blood, which is distinctly alkaline in its reaction, it is impossible for the gastric juice to have any effect upon it. The immense vascularity of the lining membrane of the stomach, particularly during digestion, is in itself almost a sufficient argument in favor of this explanation. A tissue thus permeated with an alkaline fluid, which can never be neutralized during life, because it is constantly changing, cannot be digested by the gastric juice. It is difficult to support this view with experiments which are not open to objection; and, undoubtedly, the strongest arguments in favor of it lie in the known conditions necessary to digestion in the stomach. In the case of the legs of the frog and the ear of the rabbit, which were digested in the stomach of the dog while the circulation in the parts was not interrupted, the quantity of blood, in the first instance, is so small, and the circulation so languid, that it could readily be neutralized; and the vascularity of the ear, in the second instance, is so slight, that it can easily be conceived to be inadequate to the protection of the tissues. Pavy has shown that the stomach is digested during life in rabbits after the application of ligatures at the cardiac and pyloric extremities, the supply of blood being further cut off by ligatures applied to the

[1] *Op. cit.*, p. 163.

vessels passing to this organ. He has likewise shown that when the circulation is arrested during life in a portion of the stomach by drawing it up and applying a ligature, the portion thus constricted will be acted upon by the gastric juice.[1] It must be remembered, however, that in both these experiments, the inevitable result of the operation must be to diminish or arrest the nutritive processes, and thus produce substantially the same condition which obtains after death. It is not apparent, indeed, how any operation can be performed on a living animal by which the circulation of the blood in the walls of the stomach, or any part of the organ, will be interrupted, without arresting the nutritive process in the part; for these depend entirely upon a proper and constant supply of the circulating fluid. Experiments have already sufficiently well demonstrated the influence of different degrees of acidity upon the digestive activity of the gastric juice. It is evident that after death, when the circulation is arrested, if any considerable quantity of gastric juice should be present in the stomach, the alkalinity of the small quantity of blood which remains in the vessels is neutralized, and offers no obstacle to the solvent action of the fluid, provided the proper temperature be maintained.

In endeavoring to give a satisfactory answer to the question why the stomach is not acted upon by its own secretion during life, it is impossible to ignore a similar inquiry which presents itself with regard to the small intestine and the secretions which are poured into its cavity. The intestinal secretions are undoubtedly capable of digesting, to a certain extent, animal tissues, although the process is much more active when these tissues have first undergone preparation in the stomach. The alkaline reaction of the blood cannot be regarded as the condition protecting the coats of the intestines from digestion during life, for the digestive fluids in this portion of the alimentary canal are themselves alkaline. Is there, then, any assignable reason, aside from the alka-

[1] *Op. cit.*

linity of the blood, why animal tissues are digested in the alimentary canal, while the coats of the canal itself are protected? Taking into consideration all the facts relating to this subject, the following seem to be the most rational conclusions:

Although, during life, the secretions discharged into the alimentary canal will digest the various articles of food without attacking the canal itself, after death, the accumulation in the stomach is frequently sufficient to digest the coats of the organ, causing perforation and escape of its contents, and acting sometimes upon contiguous parts. The accumulation in the jejunum, where intestinal digestion is most active, is never considerable; for digestion is here complete and rapid, and absorption follows immediately. It is impossible to say whether, if the digestive fluids should remain in quantity in this part after death, post mortem digestion of the intestines would or would not take place.

In the living stomach, the circulation of a great quantity of an alkaline fluid is an effectual barrier to the solution of its tissues by the gastric juice; for acidity is an indispensable condition to the action of this fluid upon any substance. This condition of the tissues would not, however, protect the walls of the small intestine from the action of the alkaline fluids poured into its cavity.

Inasmuch as digestion involves a catalytic transformation of alimentary principles into new substances with distinctly modified properties, it necessarily abolishes, for the time, all other catalytic processes. For this reason the catalytic changes incident to putrefaction are arrested by the action of the gastric juice, the more powerful process of transformation into albuminose, or peptones, taking its place. It is impossible that the digestive fluids should act upon any living part in which the catalytic changes incident to nutrition are so actively in operation as in the mucous membrane lining the alimentary canal; for these involve a constant supply of new material, with removal of effete matter, which

takes place with much more rapidity than is consistent with the gradual permeating and solvent action of any of the digestive fluids. These fluids could not long remain in contact with the vascular tissues, but would be carried away in the torrent of the circulation. The digestion of parts of a living cold-blooded animal, in which the processes of nutrition are very slow, or slightly vascular parts of a warm-blooded animal, is not inconsistent with this supposition.[1]

Circumstances which influence Stomach-Digestion.

The various conditions which influence stomach-digestion, except those which relate exclusively to the character or the quantity of food, operate mainly by influencing the quantity and quality of the gastric juice. It is seldom, if ever, that temperature has any influence; for the temperature of the stomach in health does not present variations sufficient to have any marked effect on digestion. Experiments in artificial digestion have shown that alimentary substances are most vigorously acted upon when maintained in contact with gastric juice at or near 100° Fahr.

As a rule, gentle exercise, conjoined with repose or agreeable and tranquil occupation of the mind, is more favorable to digestion than absolute rest. Violent exercise or severe mental or physical exertion is always undesirable immediately after the ingestion of a large quantity of food, and, as a matter of common experience, has been found to retard digestion. These facts have also been experimentally demonstrated by Beaumont in the case of St. Martin.[2] Sleep, if light and taken in the sitting posture, seems almost necessary to easy digestion in many persons; but it should be continued for only a few minutes. A prolonged and deep

[1] If gastric juice be injected under the skin of a living animal, as was done by Bernard (*op. cit.*, p. 407), solution of the areolar tissue, which is non-vascular, and in which the nutritive processes possess very little activity, takes place, and the more vascular and highly organized parts are not attacked.

[2] *Op. cit.*, p. 94.

sleep immediately after a full meal is almost always injurious, and extraordinary heaviness at that time is generally an indication that too much food has been taken.

The effects of sudden and considerable loss of blood upon stomach-digestion are very marked. After a full meal, the whole alimentary tract is deeply congested, and this condition is undoubtedly necessary to the secretion, in proper quantity, of the various digestive fluids. When the entire quantity of blood in the economy is greatly diminished from any cause, there is a difficulty in supplying the amount of gastric juice necessary for a very full meal, and disorders of digestion are apt to occur, especially if a large quantity of food has been taken. This is also true in inanition, when the quantity of blood is greatly diminished. In this condition, although the system constantly craves nourishment and the appetite is frequently enormous, food should be taken in small quantities at a time.

As a rule, children and young persons digest food which is adapted to them more easily and in larger relative quantity than those in adult life or in old age; but ordinarily, in old age, the digestive processes are carried on with more vigor and regularity than the other vegetative functions, such as general assimilation, circulation, or respiration.

Influence of the Nervous System on the Stomach.—It is well known that mental emotions frequently have a marked influence on digestion; and this, of course, can take place only through the nervous system. Of the two nerves which are distributed to the stomach, the pneumogastric has been the more carefully studied, experiments upon the sympathetic being difficult and unsatisfactory. Though the complete history of the influence of the pneumogastric nerves upon digestion belongs to the section on the nervous system, it will be interesting in this connection to consider briefly some of the facts which have been ascertained with regard to the influence which these nerves exert upon the stomach.

It will not be necessary to discuss the opinions of the earlier experimenters upon the influence of section of the pneumogastric nerves in the neck on stomach-digestion; as their experiments were made in ignorance of the fact that division of these nerves paralyzes the œsophagus, and renders the deglutition of most of the articles of food impossible. After section of the nerves in the neck, acts of deglutition are apparently performed, but the food collects in and distends the paralyzed œsophagus, and does not pass to the stomach.[1] It is not surprising, therefore, that the first experiments upon the influence of the pneumogastrics on digestion should have been contradictory, some contending that section of the nerves arrested stomach-digestion, while others maintained that the nerves had little or no influence upon the stomach. It is evident that without an appreciation of the effects of section of the pneumogastrics upon deglutition, observations on the influence of their section upon stomach-digestion would be of little value.

The recent experiments of Longet seem to show that while section of the pneumogastrics in the neck undoubtedly diminishes the secretion of gastric juice, the production of this fluid is not entirely arrested. He states that in dogs, one or two days after section of the nerves, he found the lacteals filled with chyle after milk had been passed into the stomach; but it is now well known that chyle is in great part, if not entirely, formed in the intestinal canal, without the intervention of the stomach. Another experiment, however, is more interesting. After section of the pneumogastrics, having ex-

[1] This observation, first made by Bouchardat and Sandras, in 1847, has since been confirmed by many experimenters. Bernard, after dividing the pneumogastrics in the middle region of the neck in a dog which had a large gastric fistula, gave the animal soup and sugared milk, which he ate with difficulty, and made many efforts to swallow; but the matters did not pass into the stomach, and were soon regurgitated by the mouth (*Leçons sur la Physiologie et la Pathologie du Système Nerveux*, Paris, 1858, tome ii., p. 422). This was one of many experiments made by Bernard with the same results (*Leçons de Physiologie Expérimentale*, Paris, 1856, p. 435).

posed the mucous membrane of the stomach, he found that an acid fluid appeared in parts which were subjected to mechanical or galvanic irritation.[1] The general results of his experiments on this subject were that after the division of both pneumogastric nerves, small quantities of food could be digested in the stomach, but that a considerable mass was only chymified on the surface, the centre not undergoing any alteration. This he attributes, not so much to arrest of secretion of the gastric juice, as to paralysis of the movements of the stomach, which, when the mass of food is considerable, are necessary in order to expose all parts to the action of the gastric juice.[2]

The experiments of Bernard on this subject are very clear and satisfactory. When the mucous membrane of the stomach was turgid with blood, the animal (a dog) being in full digestion and provided with a large gastric fistula so that the changes which might take place in the stomach could be readily observed, the pneumogastrics were divided in the neck. At once the mucous membrane became pale and flaccid, and the secretion of gastric juice was arrested. When the animal died after section of the pneumogastrics during digestion, it was remarked that the absorption of chyle seemed to have been arrested, the lacteals being found to contain coagulated chyle even as far as the villi of the intestines.[3] According to these experiments, the action of gastric juice which might exist in the stomach at the time of section of the pneumogastrics would continue, but no new fluid is secreted; and if the fluid thus remaining in the stomach be neutralized, digestion is immediately arrested. In one experiment in which the pneumogastrics had been divided, having previously emptied the stomach, Bernard introduced meat finely divided. The next day the meat had

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 235.
[2] *Op. cit.*, p. 237.
[3] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 438.

a distinctly ammoniacal odor and an alkaline reaction, as the result of spontaneous decomposition.[1]

These experiments show only an immediate arrest of the secretion of the gastric juice. In certain exceptional instances in which animals survive the section of both nerves for a number of days, or sometimes even recover, it has been noted that after a few days an acid secretion again takes place in the stomach.[2]

Though much confusion exists in the earlier observations on the effects of section of the pneumogastrics upon the stomach, the conclusions to be drawn from more recent experiments are tolerably definite.

There can be no doubt that division of both these nerves produces immediate and grave disorder in the process of stomach-digestion, amounting, it is more than probable, to complete arrest of the secretion of the gastric juice. Its secretion may be induced again by local stimulation, but the quantity is always greatly diminished. Under these circumstances, it is possible that very small quantities of food may be digested in the stomach a day or two after the operation; and if the animal survive for a considerable time,[3] the secretion may be to a certain extent reëstablished. Serious trouble in stomach-digestion is produced by the paralysis of the muscular coats of the stomach consequent upon section of both pneumogastrics.

[1] BERNARD, *Leçons sur la Physiologie et la Pathologie du Système Nerveux*, Paris, 1858, tome ii., p. 418.

[2] Ibid.

[3] One of the animals operated upon by Bernard lived for seventeen days

CHAPTER X.

MOVEMENTS OF THE STOMACH.

Character of the contractions of the muscular coat of the stomach—Movements in the cardiac and in the pyloric portion—Mechanism of the movements of the stomach—Rumination, and regurgitation from the stomach—Rumination in the human subject—Vomiting—Mechanism of vomiting—Condition of the stomach during the act of vomiting—Action of the diaphragm in vomiting—Action of the abdominal muscles in vomiting—Action of the œsophagus in vomiting—Summary of the muscular action which takes place in vomiting—Eructation.

As the articles of food are passed into the stomach by the acts of deglutition, the organ gradually changes its form, size, and position. When the stomach is empty, the opposite surfaces of its lining membrane are in contact in many parts, and are thrown into numerous longitudinal folds. As the organ is distended, these folds are effaced, the stomach itself becoming more rounded; and as the two ends with the lesser curvature are comparatively immovable, the whole organ undergoes a movement of rotation, by which the anterior face becomes superior, and is applied to the diaphragm. At this time the great pouch has nearly filled the left hypochondriac region, and the greater curvature looks anteriorly, and comes in contact with the abdominal walls.

Aside from these changes, which are merely due to the ingestion of food, the stomach undergoes important movements, which continue until its contents have been dissolved and absorbed, or have passed out at the pylorus. But while these movements are taking place, the two orifices are guarded, so that the food shall remain for the proper time exposed

to the action of the gastric juice. We have already noted the rhythmical contractions of the lower extremity of the œsophagus, by which regurgitation of food is prevented;[1] and the circular fibres, which form a thick ring at the pylorus, are constantly contracted, so that, at least during the first periods of digestion, only liquids and that portion of food which has been reduced to a pultaceous consistence can pass into the small intestine. It is well known that this resistance at the pylorus does not endure indefinitely, for indigestible articles of considerable size, such as stones, have been passed by the anus after having been introduced into the stomach; but observation has shown that masses of digestible matter are passed by the movements of the stomach to the pylorus over and over again, and do not find their way into the intestine until they have become softened and broken down.

The contractions of the walls of the stomach are of the kind characteristic of the non-striated muscular fibres. If the finger be introduced into the stomach of a living animal during digestion, it is gently but rather firmly grasped by a contraction which is slow and gradual, enduring for a few seconds, and as slowly and gradually relaxing and passing to another part. The movements during digestion undoubtedly present certain differences in different animals; but there can be no doubt that the phenomenon is universal, in spite of the experiments of some physiologists anterior to the time of Haller, who exposed the organ and always found it passive. In dogs, when the abdomen is opened soon after the ingestion of food, the stomach appears pretty firmly contracted on its contents. In a case reported by Todd and Bowman, in the human subject, in which the stomach was very much hypertrophied and the walls of the abdomen were very thin, the vermicular movements could be distinctly seen. These movements were active, resembling the peristaltic movements of the intestines, for which, indeed,

[1] See page 204.

they were mistaken, as the nature of the case was not recognized during life.[1] No argument, therefore, seems necessary to show that during digestion, the stomach is the seat of tolerably active movements.

A peculiarity in the movements of the stomach, which has been repeatedly observed in the lower animals, particularly dogs and cats, and in certain cases has been confirmed in the human subject, is that at about the junction of the cardiac two-thirds with the pyloric third, there is frequently a transverse band of fibres so firmly contracted as to divide the cavity into two almost distinct compartments. It has also been noted that the contractions in the cardiac division are much less vigorous than near the pylorus; the stomach seeming simply to adapt itself to the food by a gentle pressure as it remains in the great pouch, while in the pyloric portion, divided off as it is by the hour-glass contraction above-mentioned, the movements are more frequent, vigorous, and expulsive. We must again refer, however, to the observations of Beaumont for the only accurate description of the movements of the stomach, as they take place during digestion in the human subject.

The experiments of Beaumont were generally made with the subject lying on the right side, and the movements of the stomach were observed by following with the eye a particular morsel of food as it passed along, or by introducing the bulb of a thermometer into the organ, and allowing it to move with the alimentary mass. It was invariably found that the movements of the thermometer-bulb were the same as those observed by identifying and following a particular portion of food. As the alimentary bolus enters by the cardiac opening, it turns to the left, descends into the great pouch, and follows the greater curvature to the pyloric end. It then returns to the cardiac orifice by the lesser curvature, and takes again the same course as before. While these revolutions, so to

[1] TODD AND BOWMAN, *The Physiological Anatomy and Physiology of Man*, Philadelphia, 1857, p. 550

speak, of the alimentary mass are going on, the food is turned over and over, so that it becomes intimately mixed with the digestive fluids and subjected to a certain amount of trituration. This action is undoubtedly of great importance, as fresh portions of food are thereby continually exposed to the action of the gastric juice, and the boluses, with their particles agglutinated to a certain extent in the mouth, are disintegrated and penetrated with the gastric fluid in every part.

A marked difference was observed between the movements in the cardiac and in the pyloric portion. When the thermometer-bulb arrived at the contracted septum, which was three or four inches from the pyloric end, it was at first stopped by the forcible contraction; but in a short time there was a gentle relaxation which allowed it to pass, when it was drawn quite forcibly for three or four inches toward the pyloric opening. When in this portion of the stomach, the bulb was firmly grasped and made to undergo a spiral motion; and if drawn forcibly out, it gave to the fingers the sensation of being held by a strong suction force. As soon as relaxation occurs, the bulb is passed back to the seat of stricture, and when pulled through this, it moves freely in the great cavity.

Each one of these revolutions was found to occupy from one to three minutes. They were slower at first than after digestion had been somewhat advanced.[1]

The mechanism of these movements is easily appreciated when we consider the number and varied direction of the fibres which form the muscular coat of the stomach, and the fact that the stomach, when distended, is more or less displaced with every movement of the diaphragm. It is easy to understand, also, how in the pyloric portion, where the muscular fibres are thickest and the cavity is comparatively small and elongated, the movements should be more vigorous and expulsive than over the rest of the organ. We have already alluded to the fact that the movements of the stom-

[1] BEAUMONT, *op. cit.*, p. 109 *et seq.*

ach are animated by the pneumogastric nerves and become arrested when both these nerves are divided.[1]

As the result chiefly of the observations of Beaumont, the following may be taken as a summary of the physiological movements of the stomach in digestion:

The stomach normally undergoes no movements until food is passed into its cavity. When food is received, at the same time that the mucous membrane becomes congested and the secretion of gastric juice commences, contractions of the muscular coat begin, which are slow and irregular during the commencement of stomach-digestion, but become more vigorous and regular as the process advances. After digestion has become fully established, the stomach is generally divided by the firm and almost constant contraction of a transverse band of fibres into a cardiac and a pyloric portion; the former occupying about two-thirds, and the latter one-third of the length of the organ. The contractions of the cardiac division of the stomach are uniform and rather gentle; while in the pyloric division they are intermittent and more expulsive. The effect of the contractions of the stomach upon the food contained in its cavity is to subject it to a tolerably uniform pressure, with a certain amount of trituration and agitation, in the cardiac portion, the general tendency of the movement being toward the pylorus along the greater curvature, and back from the pylorus toward the great pouch along the lesser curvature. At the constricted part, which separates the cardiac from the pyloric portion, there is an obstruction to the passage of the food until it has been sufficiently acted upon by the secretions in the cardiac division to have been reduced to a pultaceous consistence. The alimentary mass then passes into the pyloric division, and by a more powerful contraction than occurs in other parts of the stomach, it is passed into

[1] The question as to how far the sympathetic system of nerves is ever concerned in the movements of the stomach will be considered in treating specially of the nervous system.

the small intestine. This completes the distinction between the two portions of the stomach, the cardiac division only, as we have already seen, possessing a mucous membrane capable of secreting the true solvent gastric juice.

The revolutions of the alimentary mass, thus accomplished, take place slowly, by gentle and persistent contractions of the muscular coat; the food occupying from one to three minutes in its passage entirely around the stomach. Every time that a revolution is accomplished, the contents of the stomach are somewhat diminished in quantity;[1] probably, in a slight degree, from absorption of digested matter by the stomach itself, but chiefly by the gradual passage of the softened and disintegrated mass into the small intestine. This process continues until the stomach is emptied, occupying a period of from two to four hours; after which, the movements of the stomach cease until food is again introduced.

Regurgitation, Vomiting, and Eructation.

Rumination and Regurgitation.—Regurgitation of part of the contents of the stomach, in the human subject, though of frequent occurrence, particularly in early life, is not strictly a physiological act; and is always due either to overloading of the stomach or some pathological condition. But in some of the inferior animals this is habitual; a certain class, called ruminants, regularly passing the food, after the first deglutition, in small quantities from the paunch into the mouth, where it undergoes a second mastication, and is only then permitted to pass to the secreting stomach and the rest of the alimentary canal. Animals of this class, examples of which are the ox, sheep, goat, and the camel and the deer tribe, are invariably herbivorous, and take into the stomach a large bulk of matter from which is elaborated a comparatively small quantity of nutriment. During the period when they are nourished by milk, rumination does not take place.

[1] BEAUMONT, *op. cit.*, p. 113.

The ordinary food taken by these animals passes, in greatest part, into the first stomach or rumen; a small portion, which consists of the moist and finely divided parts, passes into the second stomach, but none is received into the third and the fourth stomach.[1] In the first stomach, are thus collected all the dry and coarse parts of the food, which are here slowly but continuously agitated by the movements of the muscular coat. Most of the liquids taken and a considerable quantity of saliva accumulate in the second stomach, or reticulum. When the proper quantity of food has been taken, small quantities are forced by the contractions of the muscular wall into a canal or groove, which is a continuation of the œsophagus, and is bounded by two lips capable of closing over the top, so as to completely separate it from the great cavity. Here the food is moistened by fluids poured in from the second stomach, and a small bolus, moulded by the muscular contractions of the walls of the canal, is prepared to be passed back to the mouth. The bolus is then passed along the œsophagus by the anti-peristaltic contractions of its muscular

[1] All ruminating animals have multiple stomachs, generally with four distinct divisions. The first stomach, called the rumen or paunch, is the most capacious. It is generally divided into several sacs, and is lined by a mucous membrane with numerous villi, and covered by a dense layer of epithelium. The second stomach, called the reticulum, is very much smaller than the first. It presents in its mucous membrane, a large number of deep polygonal pits, like the cells of the honey-comb, and always contains a considerable quantity of liquid. There is a very free communication between the reticulum and the rumen. The third stomach, called the omasum, or psalterium, is ovoid in form, and its mucous membrane is arranged in folds like the leaves of a book, giving it a very remarkable appearance. These folds are alternately wide and narrow. The fourth stomach, called the abomasum, is the true secreting organ. It is lined by a soft, glandular mucous membrane, and resembles the single stomach of most mammals. In the camel, in addition to the above compartments, the stomach is provided with several groups of large sacs attached to the rumen. These receive only liquids, and are provided with bands of muscular fibres around their openings, so that their liquid contents may be retained and stored up for future use. In this animal, the cells of the reticulum are unusually deep, narrow at their openings, and are capable of being closed by the contraction of muscular fibres situated at their orifices.

coat, aided by a brisk, powerful, and involuntary contraction of the abdominal muscles and the diaphragm. Though this act is aided by the contractions of the œsophagus itself, it cannot be accomplished without the action of the diaphragm and abdominal muscles. This has been proven by experiments in which these muscles have been paralyzed; when rumination becomes impossible. The passage of the bolus from the rumen to the mouth takes place with great rapidity, and has nothing of the gradual character which is noted in the peristaltic movements of the intestinal canal. In the rumen, contrary to the opinion which at one time obtained, the food is only macerated in the fluids which have been swallowed, nothing being secreted in its cavity; but the position of the reticulum is such as to favor the accumulation in its cavity of fluids, consisting of salivary secretion which has been swallowed, and fluids taken as drink. There is no evidence that there is any fluid secreted in the second stomach.

When a bolus is thus brought back to the mouth, it undergoes the second mastication, which, in the ox, is generally something less than a minute in duration. At this time it is still further moistened by an abundant flow of saliva, taking place almost entirely from the parotids.

After the second mastication has been accomplished, the mass is swallowed with great rapidity; and as it is now soft, and inconsiderable in size, it does not distend the canal which passes from the œsophagus to the third stomach so as to separate the lips and escape into the rumen, but passes directly into the third stomach, or omasum. In the omasum, the food is pressed rather forcibly between the leaf-like folds of the mucous membrane, and gradually passes from this to the fourth stomach, or abomasum, which is the true stomach of these animals, and the only one which secretes the gastric juice. There is no reason to believe that any fluid is secreted in the third stomach, the contents of which are always remarkably dry.

The second deglutition is followed very soon by the pas-

sage of a new bolus to the mouth for rumination; the interval of time being very short, only from four to five seconds.[1] There is considerable difference in the length of time employed by different animals in rumination. In the ox, about one-quarter of the day is thus occupied; but in the sheep and the goat the process is much more rapid.[2]

Additional interest is attached to the function of rumination in the inferior animals, in connection with human physiology, from the fact that an analogous process has sometimes been observed in the human subject; though it is rare and generally connected with a pathological condition. Such cases have been often quoted, and, in the earlier works on physiology, were frequently exaggerated; but a few instances, well authenticated, are on record in which rumination had become habitual. A very remarkable case of this kind is reported by Home. The subject was an idiot-boy, aged nineteen years, who had an appetite so ravenous that it became necessary to restrict the quantity of food. At dinner he ordinarily ate about a pound and a half of meat and vegetables, swallowing the whole in two minutes. He began to chew the cud at the end of a quarter of an hour. The muscles of the throat could be seen to contract when the bolus was passed back to the mouth. He chewed the food by two or three movements of the jaws and then swallowed it again. This was repeated at intervals for half an hour, during which time he was always more quiet than usual. The intellect was so feeble that it was impossible to ascertain whether the rumination was voluntary or involuntary.[3] One of the cases of rumination most frequently referred to is that of M. Cambay, who studied the phenomena in his own person, and

[1] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1854, tome i., p. 527.

[2] COLIN, *op. cit.*, p. 521.

[3] HOME, *Observations on the Structure of the Stomachs of Different Animals, with a view to elucidate the Process of converting Animal and Vegetable Substances into Chyle.—Philosophical Transactions*, London, 1807, p. 174.

made it the subject of an inaugural thesis; and another is the case of the brother of M. P. Bérard.[1] In these instances, as far as could be ascertained from the sensations during the act, the regurgitation of food was effected by persistent contractions of the muscular walls of the stomach, assisted by a slight and almost involuntary contraction of the abdominal muscles and diaphragm. It is stated by Cambay that in his case, the taste of the articles of food was not modified, "but that it is with something of a sense of pleasure that the ruminator thus causes to return to the mouth the aliments that he has taken into the stomach, which makes them undergo a new trituration."[2]

Rumination in the human subject is not a physiological act. It is evident that the substances returned to the mouth are not impregnated with the gastric juice, for they have not the disagreeable acid taste of ordinary vomited matters. The acts are generally preceded by a sense of fulness in the stomach, and their mechanism is probably nearly the same as that of the regurgitation of small quantities of milk from the distended stomachs of young children, which is so common. In the person of Cambay, the first act was said to be voluntary, but succeeding ones were not under the control of the will. Undoubtedly the faculty of regurgitating the food may be improved by practice, and we have known of an instance in which it was apparently cultivated as an accomplishment.

The mechanism of regurgitation of portions of the contents of the stomach, aside from instances simulating rumination, has been so often alluded to that it demands in this connection but a passing mention. In some persons, this act may be accomplished by a voluntary muscular effort, especially when the stomach is overloaded. It occasionally happens, when the stomach is somewhat distended, that a small

[1] BÉRARD, *Cours de Physiologie*, Paris, 1849, tome ii., p. 274.

[2] CAMBAY, *Thèse sur le Mérycisme et la Digestibilité des Alimens.—Thèses de l'École de Médecine*, Paris, 1830, tome vii., No. 213, p. 10.

portion of its contents suddenly finds its way to the mouth without even the consciousness of the individual. The muscular contraction which produces this slight regurgitation is so insignificant that there must necessarily have been some relaxation at the cardiac opening of the stomach, which under ordinary conditions is, as we know, firmly closed. The act is then produced, in part by a slight contraction of the abdominal muscles and diaphragm, and in part by contractions of the stomach itself and anti-peristaltic movements of the œsophagus. It has nothing of the violent expulsive character of true vomiting.

Vomiting.[1]—The mechanism of vomiting was the subject of much discussion among physiologists in the early part of the present century, when the celebrated experiments of Magendie on this subject were first made. Though Magendie was by no means the first to demonstrate the view which now generally obtains regarding the muscular actions concerned in vomiting, his experiments were of such a striking character, and so demonstratively conclusive, as to attract the attention of all physiologists, and to settle, almost beyond doubt, a question which had before been very uncertain. The experiments of Bayle, Chirac, Schwartz, and others, which tended to prove that vomiting is due to contractions of the abdominal muscles and diaphragm, compressing the stomach, and not to contractions of the muscular tissue of the stomach itself, had been recognized and the conclusions adopted by some physiologists, long before the publication of Magendie's experiments, in 1813. For example, John Hunter, in the second edition of his *Animal Œconomy*, published in 1792, says: "We know that the action of vomiting is performed entirely by the diaphragm and abdominal muscles."[2]

[1] A sufficient apology for considering the act of vomiting (which is undoubtedly pathological), so fully as is done in the succeeding pages, is in the fact that its mechanism is usually treated of in works upon physiology, and is not considered in treatises upon practical medicine.

[2] HUNTER, *Observations on Certain Parts of the Animal Œconomy*, London, 1792, p. 199.

Nevertheless, the general opinion was, with Haller,[1] that in vomiting, the stomach was emptied chiefly by convulsive contractions of its intrinsic muscles.

An excellent review of the experiments on the mechanism of vomiting, anterior to the memoir of Magendie, is contained in the report of the commission from the *Institut*, to which the subject was referred. The first observations on the subject were those of Bayle, made in 1681;[2] these were followed by the confirmatory experiments of Chirac, in 1686, the later experiments of Schwartz, and many others.[3] The experiments of Bayle consisted in giving animals emetics in solution in water, and making an incision into the abdomen, so that when the animal made efforts at vomiting, the finger could be introduced and placed upon the stomach. When this was done, it became evident that the stomach did not contract during the act by which its contents were expelled; and when the abdomen was largely opened, so that the stomach could not be compressed between the diaphragm and the abdominal muscles, vomiting was impossible. That these experiments had been recognized by physiologists, is shown by the passage just quoted from the works of Hunter.

We can give no better idea of the actual mechanism of vomiting than by a brief analysis of the memoir of Magendie, with the various experimental facts by which the views advanced by him were supported. The first two experiments were merely repetitions of those performed long before by Bayle and Chirac. After having caused a dog to swallow six grains of tartar emetic, when nausea had been excited, an incision was made in the median line and the finger was introduced into the abdominal cavity and placed upon

[1] HALLER, *Elementa Physiologiæ*, Bernæ, 1764, tomus vi., pp. 281, 282.

[2] MAGENDIE, *Mémoire sur le Vomissement, lu à la première classe de l'Institut de France.*—Suivi du Rapport fait à la classe par MM. Cuvier, Humboldt, Pinel, et Percy, Paris, 1813, p. 27.

[3] HALLER, *op. cit.*, tomus vi., p. 228. Schwartz went further than his predecessors, and showed that the cardiac opening of the stomach was relaxed during vomiting.

the stomach. At each nausea, the finger was compressed, but the stomach seemed passive; and when vomiting took place and part of the contents of the stomach was discharged, the finger was "compressed with a force really extraordinary." The incision in the abdomen was then enlarged so that the stomach could be seen. The stomach became distended with air at each nausea, and when vomiting occurred again, it was compressed without presenting the slightest contraction of its intrinsic muscular fibres. The air with which the stomach was distended before each act of vomiting evidently was introduced by the œsophagus, as was shown by experiments which have been already quoted.[1] In another experiment, four grains of emetic were injected into the jugular of a dog, a large incision was made into the abdomen, and the stomach was drawn entirely out so as to be removed from the pressure of the muscles. Though the animal made violent efforts at vomiting, the contents of the stomach were undisturbed, and the organ remained perfectly motionless and flaccid. Vomiting was then produced by vigorous pressure of the stomach, outside of the abdomen, with the hands. In another experiment, the stomach was drawn out of the abdomen, the vessels carefully ligated, and the organ extirpated. Into the abdomen was then introduced a small pig's bladder, to the neck of which was fixed a gum-elastic tube, which was passed into the œsophagus and secured in that position by threads. About a pint of water was then introduced into the bladder which was made to take the place of the stomach, and the wound in the abdomen was closed with points of the interrupted suture. Emetic was then injected into the veins, and in a few moments efforts at vomiting supervened, and the contents of the bladder were discharged by the mouth. These remarkable experiments proved conclusively the want of action of the stomach itself in vomiting, and the mechanism of the discharge of its contents by compression exerted upon it by the abdominal mus-

[1] See page 207.

cles and the diaphragm. Other experiments were made, however, which demonstrated the relative importance of the different muscles in the performance of this act. The phrenic nerves were divided in a dog, and the diaphragm was thus rendered almost inert. On injecting emetic into the veins after this operation, vomiting took place at times very feebly, and at times not at all. In another animal, the abdominal muscles were divided, leaving the viscera confined by the peritoneum and the linea alba. Emetic was then injected into the circulation, and vomiting was effected solely by contractions of the diaphragm. In this experiment, after having divided the phrenic nerves, vomiting ceased, though the nausea continued.

These experiments, which were satisfactorily repeated before a commission from the *Institut*, consisting of Cuvier, Humboldt, Pinel, and Percy, are as conclusive as any that ever have been made upon living animals. Since their publication, they have been repeated by a number of physiologists, among whom may be mentioned Bégin,[1] Legallois, and Béclard.[2] We are also enabled to testify to their accuracy from personal observation; and in the fall of 1861 they were in part repeated in the course of lectures on physiology before the class of the Bellevue Hospital Medical College, and an animal was caused to vomit from a pig's bladder which had been substituted for the stomach.[3]

If any thing further were needed to establish the great importance of the action of the abdominal muscles and diaphragm in vomiting, and the insignificant part played by the stomach itself in this operation, it could be furnished by facts relating to the mode of contraction of the muscular fibres which constitute the middle coat of the stomach, and

[1] *Dictionnaire des Sciences Médicales*, in 60 vols., Paris, 1822, tome lviii., Article *Vomissement*.

[2] Legallois, *Expériences sur le Vomissement.—Œuvres*, Paris, 1824, tome ii., p. 93 *et seq.*

[3] These experiments were made simply for class-demonstration, and have never before been published.

cases of disease in which it has been impossible for contractions of the stomach to take place. It is well known that the characteristic mode of contraction of the striated, voluntary muscles is rapid, violent, and followed by sudden relaxation; and that where it becomes necessary, in the performance of any of the vegetative functions, that such muscular action should take place, as in the action of the heart in propelling the blood forcibly into the arterial system, the striated muscular fibre is found. On the other hand, the characteristic mode of contraction of the non-striated, involuntary muscular fibre is gradual, enduring for a certain time, and followed by a slow relaxation. These facts point at once to the kind of muscles which we would suspect to be engaged in the production of vomiting. The act is always violent, sudden, and convulsive, and is entirely inconsistent with the mode of contraction of non-striated muscles, as it has been observed in other situations.

A remarkable case is mentioned by Longet, in which a young girl, with the intent to commit suicide, swallowed a large quantity of a mineral acid. She vomited continually up to the time of her death; and in the vomited matters were found numerous shreds of the coats of the stomach. At the autopsy it was found that the stomach had been destroyed, except little portions of its walls, which were adherent to the surrounding parts. These were united to the adjacent viscera and the walls of the abdomen by inflammatory exudation, so as to form a cavity which was not a stomach, but which communicated freely with the œsophagus. Yet this patient, without a contractile stomach, vomited freely during the last hours of her life.[1]

A case of extrusion of the stomach, reported by Lépine, in 1844,[2] is often misquoted so as to make it appear that the

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 141.

[2] LÉPINE, *Plaie pénétrante de l'abdomen ayante donné issue à l'estomac, à l'arc du colon, et à l'épiploon, guérie en vingt et un jours, suivi de réflexions sur le vomissement.—Bulletin de l'Académie Royale de Médecine*, Paris, 1843–'44, p. 116 *et seq.*

contractions of the stomach itself are sufficient to produce vomiting.[1] In this case, the stomach, containing food and air, was protruded from the abdomen by a large wound. It remained motionless while violent and ineffectual efforts at vomiting were made, during the whole time that it was thus out of the abdomen, and could not be excited to contraction, even by gentle irritation; but when the stomach was returned into the abdominal cavity, vomiting instantly took place.

All the facts bearing on this subject go to show that in true vomiting, contractions of the muscular coats of the stomach are not necessary, are not definitely connected with the act, and are never capable of discharging any part of the contents of this viscus. On the contrary, the observations of Magendie seem to show that the stomach is rather relaxed than contracted during efforts at vomiting.[2]

[1] CARPENTER, *Principles of Human Physiology*, Philadelphia, 1853, p. 408, TODD AND BOWMAN, *The Physiological Anatomy and Physiology of Man*, Philadelphia, 1857, p. 565, and KIRKES, *Manual of Physiology*, Philadelphia, 1857, p. 195. These authors quote the case reported by Lépine as presenting contractions of the stomach itself, with discharge of part of its contents, while it remained out of the abdominal cavity. Brinton (*Cyclopædia of Anatomy and Physiology*, London, 1859, vol. v., supplement, p. 317) notices and corrects this error in previous quotations. The case is also correctly quoted by Dunglison (*Human Physiology*, Philadelphia, 1856, p. 205), and by Milne-Edwards (*Leçons sur la Physiologie*, Paris, 1860, p. 333).

[2] MAGENDIE, *Mémoire sur le Vomissement*, Paris, 1813, p. 12. Both Carpenter and Todd and Bowman, base their opinion that the muscular walls of the stomach are active in vomiting mainly upon the case reported by Lépine; the former quoting extensively from the original source, but the latter crediting the quotation to "Paget's Report for 1845." Carpenter says: "The stomach, having wholly protruded itself, it was seen to contract itself repeatedly and forcibly during the space of half an hour, until by its own efforts it had expelled all its contents except gases" (p. 408); and the same is said by Todd and Bowman, who speak of the reporter as L'Epione (p. 565, note). In the original account of the case referred to, there is no such statement; but, on the contrary, the reporter says (p. 148): "Thus, during all the time that the stomach remained out of the abdominal cavity, there did not take place any apparent contraction of the muscular fibres of this viscus, and nothing that it contained was expelled from its cavity, notwithstanding the violent efforts at vomiting that the patient made. Hardly

More importance is to be attached to the action of the œsophagus in vomiting than is usually assigned to it by writers. The following remark by Hunter, on this point, is interesting: "The muscles of the cavity of the abdomen act, in which is to be included the diaphragm; so that the capacity of the abdomen is lessened, and the action of the diaphragm rather raises the ribs; and there is also an attempt to raise them by their proper muscles, to make a kind of vacuum in the thorax, so that the œsophagus may be rather opened than shut, while the glottis is shut so as to let no air enter the lungs.[1] A little reflection will make it evident that the descent of the diaphragm, the most powerful of the inspiratory muscles, with the glottis firmly closed, makes a virtual vacuum in the chest, by the force of which, a canal so dilatable as the œsophagus would undoubtedly be distended. This action must powerfully assist in vomiting, by drawing the food into the œsophagus and by dilating the cardiac opening, which, as we have seen, is ordinarily closed. Experiments, particularly those of Béclard and of Legallois, have further shown that there is a violent and extensive contraction of the longitudinal fibres of the œsophagus with each act of vomiting. This was demonstrated by dividing the œsophagus near the stomach, drawing it out at a wound in the neck, and causing the animal to make efforts at vomiting, by injecting emetic into the veins. With each act, the œsophagus was observed to undergo sudden and marked contraction in its length.[2] This act assists in vomiting, as the shortening of the œsophagus has a tendency

had the stomach been returned into the belly, when the same effort produced expulsion of aliments."

It is remarkable that the authors of the above-mentioned excellent and comprehensive works upon physiology should have been content to take a quotation so important as the one in question at second-hand, when a reference to the original would have enabled them to avoid making an important statement precisely opposite to the fact.

[1] HUNTER, *op. cit.*, p. 200.

[2] LEGALLOIS, *Œuvres*, Paris, 1824, tome ii., p. 91.

to dilate the cardiac opening of the stomach and counteract the contraction of the pillars of the diaphragm.

It has been found by Magendie that during the nausea which precedes the act of vomiting, there is always distension of the stomach from deglutition of air.[1] This may be sometimes absent in the human subject, when vomiting occurs very suddenly; but in all Magendie's experiments upon animals, he found that immediately after an act of vomiting, the stomach was flaccid, but that when another effort was approaching, and during the nausea which preceded, the organ became gradually distended. Distension of the stomach from deglutition of air previous to the act of vomiting was observed in the case of extrusion of the stomach reported by Lépine.[2] It is unnecessary to repeat the observations by which it was shown that the air enters by the œsophagus; as they have already been referred to under the head of deglutition.[3]

Summary.—The symptoms which precede the act of vomiting are sufficiently familiar. Usually they commence with a peculiar sensation of depression and general *malaise*, known as nausea. This is frequently accompanied by slight pain in the region of the epigastrium, feeble pulse, cold and clammy perspiration, and pallor. There is also usually an increase in the flow of saliva. Retchings and the peculiar acts by which air is forced into the stomach are frequent, and immediately before the vomiting takes place, there is generally a violent inspiration, followed by spasmodic closure of the glottis. Violent and convulsive expulsion of a part or the whole of the contents of the stomach by the mouth, which is widely opened, then takes place. This is accomplished by spasmodic contractions of the diaphragm, the

[1] MAGENDIE, *Mémoire sur la Déglutition de l'Air atmosphérique, lu à l'Institut, le 25 octobre*, 1813, p. 4.

[2] LÉPINE, *loc. cit.*, p. 149.

[3] See page 207.

longitudinal fibres of the œsophagus, and the abdominal muscles. The muscular coats of the stomach itself are relaxed, or, at all events, their contraction has no marked influence in the expulsion of its contents.

The most important muscle concerned in this act is the diaphragm; and it has been shown that this muscle alone is capable of producing vomiting when the abdominal muscles have been divided.[1] The action of the diaphragm is to forcibly press the stomach against the anterior wall of the abdomen and the linea alba, at the same time, by its descent, forming a tendency to a vacuum in the chest and dilating the œsophagus,—as the air cannot enter the lungs, owing to closure of the glottis. The contractions of the longitudinal fibres of the œsophagus are probably important in assisting to relax the cardiac opening of the stomach, counteracting, at the same time, the contractions of the pillars of the diaphragm. The contractions of the abdominal muscles assist in expelling the contents of the stomach, but are much less effectual than the contractions of the diaphragm. It has been shown that they are frequently incapable, in themselves, of producing vomiting when the diaphragm has been paralyzed. They always act, however, as can be readily observed by simple external examination.

The vomited matters pass readily into the mouth, and seldom, if ever, into the glottis, which is firmly closed. The velum is generally contracted and applied to the pharynx so as to protect the nasal passages; but this is not always effectual, for matters sometimes pass into the nose when the act is very sudden or when the mouth is not sufficiently opened.

After the act has been accomplished by one, or several successive contractions, it is followed immediately by a prolonged expiration and a sense of relief from the distressing nausea. It is frequently repeated, however, at intervals

[1] In birds, the abdominal muscles perform the most important part in vomiting.

more or less remote, when the phenomena take place in the order just described.

The act of vomiting is undoubtedly induced by causes which operate through the nervous system, and a full consideration of these properly belongs to another division of this work. The impression produced by the irritant emetics is conducted to the nervous centre and gives rise to a stimulus which is sent to the muscles concerned in the act. The transmission takes place in part through the pneumogastrics, though this is not the only channel, for vomiting may be thus induced after division of these nerves. It is by no means necessary that an impression should be made upon the stomach, as is shown by efforts at vomiting after the stomach has been extirpated. Irritation of some of the sympathetic nerves, particularly the abdominal ganglia, will produce vomiting. Traction upon the œsophagus, the irritation produced by biliary calculi, uterine disorders, etc., may produce the same result. Vomiting is very common in cerebral disturbances; and this is undoubtedly the first cause of ordinary sea-sickness. When vomiting results from titillation of the fauces, the impression is conveyed to the nervous centre and is reflected to the muscles concerned, in the same way. These facts show that there are many avenues for the passage of these impressions to the nervous centres. The action of emetics which operate through the blood is not reflex, but the vomiting is probably induced by the direct impression made by these substances on the nervous centres.

Eructation.—The discharge of gases from the œsophagus by the mouth, accompanied with a peculiar and characteristic sound, is very common. This is usually accomplished without any marked effort of the muscles concerned in vomiting, and evidently requires very little force. Usually, the cardia is so effectually closed as to prevent the passage even of gases; and in eructation, there must be a temporary relaxation of this opening. When thus relaxed, the act is accom-

plished chiefly by contractions of the stomach and œsophagus. It is generally accompanied or preceded by sensible convulsive movements of the œsophagus, involving, possibly, contractions of its longitudinal fibres, which would favor relaxation of the cardiac opening. Though usually involuntary, this act is sometimes under the control of the will. When it occurs, while it is difficult or impossible to prevent the discharge of the gas, the accompanying sound may be readily suppressed. Eructation is frequently a matter of habit, which in many persons becomes so developed by practice, that the act may be performed voluntarily at any time.

CHAPTER XI.

INTESTINAL DIGESTION.

Physiological anatomy of the small intestine—Size of the small intestine—Divisions of the small intestine—Mucous membrane of the small intestine—Valvulæ conniventes—Glands of Brunn—Intestinal tubules, or follicles of Lieberkühn—Intestinal villi—Solitary glands, or follicles, and the patches of Peyer—Intestinal juice—Secretion of the solitary and agminated glands—General properties of the intestinal juice—Action of the intestinal juice in digestion.

Physiological Anatomy of the Small Intestine.

The small intestine, so called on account of its small size as compared with the rest of the intestinal tract, is the long cylindrical tube which occupies the greatest part of the abdominal cavity. This must now be regarded as the most important division of the digestive system; and its physiological anatomy, together with that of the great glands which discharge their secretions into its cavity, are indispensable as an introduction to the study of intestinal digestion. As it is in the small intestine that the final elaboration of most of the alimentary principles takes place, and here also that these principles are taken into the circulating fluid, we will find, in our study of its anatomy, certain parts which are concerned in digestion, and others which, as far as we know, are connected only with the function of absorption. It will be most convenient, however, to consider, in this connection, all the structures found in the small intestine, which possess physiological interest.

The small intestine, extending from the pyloric extremity of the stomach to the ileo-cæcal valve, is held to the

spinal column by a double fold of serous membrane, called the mesentery. As the peritoneum which lines the cavity of the abdomen passes from either side to the spinal column, it comes together in a double fold just in front of the great vessels along the spine, and passing forward, splits again into two layers, which become continuous with each other and enclose the intestine, forming its external coat. The width of the mesentery is usually from three to four inches; but at the commencement and the termination of the small intestine, it suddenly becomes shorter, binding the duodenum and that portion of the intestine which opens into the caput coli closely to the subjacent parts. The mesentery thus keeps the intestine in place, but allows of a certain amount of motion, so that the tube may become convoluted, accommodating itself to the size and form of the abdominal cavity. The form of these convolutions is irregular and is continually changing.

The length of the small intestine, *in situ*, is probably from fifteen to eighteen feet;[1] but the canal is very distensible, and its dimensions are subject to constant variations. When separated from the mesentery, and measured without stretching, its length has been found to be, on an average, about twenty feet. Its diameter is about one and a quarter inches.[2]

This part of the alimentary canal has been divided into three portions, which present anatomical and physiological peculiarities, more or less marked. These are the duodenum, the jejunum, and the ileum.

The duodenum has received its name from the fact that

[1] See page 134, note.

[2] Dr. Brinton made the last-named estimates from measurements of something less than forty human intestines. "In making these, the healthy intestine was laid upon a board, and spread out to what seemed a proper width, before taking its length. (*Cyclopædia of Anatomy and Physiology*, London, 1859, vol. v., supplement, p. 340.) Sappey, from measurements in four cases, estimates the length of the small intestine at about twenty-six feet. (*Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 124.)

it is about the length of the breadth of twelve fingers, *i. e.*, from eight to ten inches. This portion of the intestine is considerably wider than the constricted pyloric end of the stomach, with which it is continuous, and is also much wider than its continuation, the jejunum. It presents a curve, which is ordinarily described by anatomists as consisting of three portions. The first, called the hepatic or ascending portion, is about two inches in length. This is much less firmly fixed by its peritoneal attachment than the other portions, and is nearly covered by the serous membrane. Its direction is outward, backward, and slightly upward. Turning downward, and a little inward, it merges into the second, called the descending or vertical portion, the length of which is about three inches. This is covered with peritoneum only on its anterior surface, and is somewhat more firmly attached than the ascending portion. The intestine then makes a second bend, and the third or the transverse portion is horizontal in its course, passing across the spine into the left hypochondrium. This portion is about five inches in length. It is narrower than the others, is but partially covered by peritoneum, and is more firmly bound down than any other part of the small intestine.

The coats of the duodenum, as of the other divisions of the intestinal tube, are three in number. Commencing externally, we have the serous, or peritoneal coat, which has already been described. The middle, or muscular coat, is composed of the involuntary or unstriped muscular fibres, such as exist in the stomach, arranged in two layers. The external, longitudinal layer is not very thick, and the direction of its fibres can be made out easily, only at the outer portions of the tube, opposite the attachment of the mesentery. Near the mesenteric border, the fibres are very faint. This is true throughout the whole of the small intestine; though the fibres are most numerous in the duodenum. The internal, circular, or transverse layer of fibres is considerably thicker than the longitudinal layer. These fibres encircle

the tube, running, for the most part, at right angles to the external layer, but some of them having rather an oblique direction. The circular layer is thickest in the duodenum; diminishing gradually in thickness to the middle of the jejunum, but after that maintaining about a uniform thickness throughout the canal, to the ileo-cæcal valve.

The jejunum, the second division of the small intestine, is continuous with the duodenum. It presents no well-marked line of separation from the third division, but is generally considered to include the upper two-fifths of the small intestine, the lower three-fifths being called the ileum. It has received its name from the fact that it is almost always found empty after death. This portion of the intestine presents no important peculiarities as regards its peritoneal and muscular coat.

The ileum is somewhat narrower and thinner than the jejunum; otherwise possessing no marked peculiarities except in the structure of its mucous membrane. This opens into the commencement of the colon, and is the termination of the small intestine.

Mucous Membrane of the Small Intestine.—The mucous coat of the small intestine is somewhat thinner than the lining membrane of the stomach. It is thickest in the duodenum, and gradually becomes thinner till we reach the ileum. It is highly vascular, presenting, like the mucous membrane of the stomach, a great increase in the quantity of blood during the process of digestion. It has a peculiar soft and velvety appearance, and during digestion, is of a vivid red color, being pale pink during the intervals. It presents for anatomical description the following parts: 1, folds of the membrane, called valvulæ conniventes; 2, duodenal racemose glands, or the glands of Brunn; 3, intestinal tubules, or the follicles of Lieberkühn; 4, intestinal villi; 5, solitary glands or follicles; 6, agminated glands, or the patches of Peyer.

The valvulæ conniventes, simple transverse duplicatures of the mucous membrane of the intestine, are particularly well marked in man, though they are found in some of the inferior animals belonging to the class of mammals, as the elephant and the camel.[1] They render the extent of the mucous membrane much greater than that of the other coats of the intestine. Commencing at about the middle of the duodenum, they extend, with no diminution in number, throughout the jejunum. In the ileum they become more and more rare, until they are lost at about its lower third. Sappey found about six hundred of these folds in the first half of the small intestine, and from two hundred to two hundred and fifty in the lower half. He estimates that in those portions of intestine where they are most abundant, they increase the length of the mucous membrane to about double that of the tube itself; but in the ileum they do not increase the length more than one-sixth.[2] The folds are always transverse and occupy usually from one-third to one-half of the circumference of the tube, though a few may extend entirely around it. The greatest width of each fold is in the centre, where it measures from a quarter to half an inch. From this the width gradually diminishes until the folds are lost in the membrane as it is attached to the muscular coat. Between the folds are found fibres of connective tissue similar to that which attaches the membrane throughout the whole of the alimentary tract. This, though loose, is constant, and prevents the folds from being effaced, even when the intestine is distended to its utmost. Between the folds are also found vessels, nerves, and lymphatics.

The position and arrangement of the valvulæ conniventes is such that they move freely in both directions, and may be applied to the inner surface of the intestine either above or below their line of attachment. It is evident that the food,

[1] MILNE-EDWARDS, *Leçons sur la Physiologie et l'Anatomie Comparée*, Paris, 1860, tome vi., p. 393.

[2] SAPPEY, *Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., pp. 134, 135

as it passes along in obedience to the peristaltic movements, must, by insinuating itself beneath the folds and passing over them, be exposed to a greater extent of mucous membrane than if these valves did not exist. This is about the only definite use which can be assigned to them. They cannot, as has been supposed by some, have any considerable influence on the rapidity of the passage of the alimentary mass along the intestinal canal.

Thickly set beneath the mucous membrane in the first half of the duodenum, and scattered here and there throughout the rest of its extent, are the duodenal racemose glands, or the glands of Brunn. These are not found in other parts of the intestinal canal. In their structure, they closely resemble the racemose glands of the œsophagus. On dissecting the muscular coat from the mucous membrane, they may be seen with the naked eye in the areolar tissue, in the form of little rounded bodies, about one-tenth of an inch in diameter. Examined microscopically, these bodies are found to consist of a large number of short blind tubes ramifying in every direction and held together by a small quantity of fibrous tissue. The tubes have blood-vessels ramifying on their exterior and are lined with glandular epithelium. They collect together to terminate in an excretory duct which penetrates the mucous membrane and opens into the intestinal cavity. When these structures are examined in a perfectly fresh preparation, the excretory duct is frequently found to contain a clear viscid mucus, of an alkaline reaction. This secretion has never been obtained in quantity sufficient to admit of the determination of its chemical or physiological properties. Its quantity must be infinitely small compared with the quantity of secretion produced by the glandular tubes found in such immense numbers throughout the intestinal tract; and it cannot be regarded as constituting an important part of the fluid known as the intestinal juice.

The intestinal tubules, or the follicles of Lieberkühn, the

most important glandular structures in the intestinal cavity are found throughout the whole of the small and large intestine. In examining a thin section of the mucous membrane, these little tubes are seen closely packed together, occupying nearly the whole of its structure. From the great extent of the membrane, it can readily be conceived that their number must be immense. Between the tubules are blood-vessels embedded in a dense stroma of fibrous tissues with numerous of the unstriped muscular fibres. In a vertical section of the mucous membrane, the only situations where the tubules are not seen are in that portion of the duodenum where the space is occupied by the ducts of the glands of Brunn, and immediately over the centre of the larger solitary glands and some of the closed follicles which are collected to form the patches of Peyer. The tubes are not entirely absent in the patches of Peyer, but are collected in rings, twenty or thirty tubes deep, which surround each of the closed follicles. A microscopical examination of the surface of the mucous membrane by reflected light shows that the openings of the tubules are between the villi.

In their anatomical characters, the tubules closely resemble the tubes of the stomach, especially those found in the pyloric portion. They are composed externally of a structureless basement membrane, and are lined with a single layer of columnar epithelium like the cells which cover the villi; the only difference being that in the tubes the cells are a little shorter. These cells never contain fatty granules, even during the digestion of fat. The central cavity which the cells enclose, which is about one-fourth of the diameter of the tube, is filled with a clear viscid fluid, which is the most important constituent of the intestinal juice. The length of the tubules is equal to the thickness of the mucous membrane, and is about $\frac{1}{75}$ of an inch. Their diameter is about $\frac{1}{360}$ of an inch. In man they are cylindrical, terminating in a single, rounded, blind extremity, which is frequently a little larger than the rest of the tube. These tubules are the chief

agents concerned in the production of the fluid known as the intestinal juice.

The intestinal villi, though chiefly concerned in absorption, are most conveniently considered in this connection. These exist throughout the whole of the small intestine, but are not found beyond the ileo-cæcal valve, though they cover that portion of the valve which looks toward the ileum. Their number is very great, and they give to the membrane its peculiar and characteristic velvety appearance. They are found on the valvulæ conniventes as well as the attached portions of the mucous membrane. In the duodenum and jejunum, they are most numerous. In these parts, there are from fifty to ninety villi to a square line, and in the ileum, from forty to seventy to a square line.[1] Sappey estimates, on an average, about fifty to the square line, and more than ten millions (10,125,000) throughout the whole of the small intestine.[2] The form of the villi varies somewhat in different animals. In the human subject, they are flattened cylinders or cones. In the duodenum, where they resemble somewhat the elevations found in the pyloric portion of the stomach, they are shorter and broader than in other situations, and are more like flattened conical folds. In the jejunum and ileum, they are in the form of long flattened cones and cylinders. As a rule, the cylindrical form predominates in the lower portion of the intestine. In the jejunum they attain their greatest length, measuring here from $\frac{1}{30}$ to $\frac{1}{20}$ of an inch in length, by $\frac{1}{70}$ to $\frac{1}{120}$ of an inch in breadth at their base.

The structure of the villi shows them to be simple elevations of the mucous membrane, provided with blood-vessels, and probably also with lacteals, or intestinal lymphatics. Externally is found a single layer of long columnar epithelial cells, resting on a structureless basement membrane.

[1] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 325.

[2] SAPPEY, *Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 140. Sappey estimated twelve to fourteen villi to a square millimetre, which gives, approximatively, about fifty to a square line.

These cells, though closely adherent to the subjacent parts during life, are easily removed after death, and are almost always destroyed and removed in injected preparations. They adhere firmly to each other, and are isolated with difficulty in miscroscopic preparations. Kölliker has shown that the membranes on the free surfaces of these cells are thickened and finely striated, forming, as it were, a special membrane covering the villus and external to the cells. This membrane may be raised up from the cells and exhibited by the action of water.[1]

The substance of the villus is composed of a stroma of amorphous matter, in which are embedded nuclei and a few fibres, fibro-plastic cells, and numerous non-striated muscular fibres. The blood-vessels are very numerous; four or five, and sometimes as many as twelve or fifteen artereoles entering at the base, ramifying through the substance of the villus, but not branching or anastamosing, or even diminishing in calibre, until by a slightly wavy turn or loop they communicate with the venous radicles, each of which is somewhat larger than the arterioles. The veins all converge to two or three branches, finally emptying into a large trunk which occupies the centre of the villus.[2]

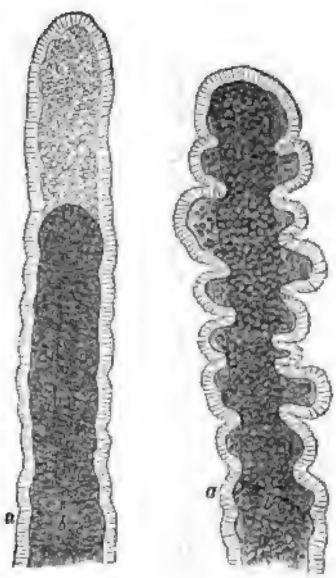
The nuclei of the muscular fibres of the villi may be shown by treating them with acetic acid after the epithelium has been removed. These fibres appear to be longitudinal, forming a thin layer surrounding the villus, about half way between the periphery and the centre, and continuous with the muscular coat of the intestine. The muscular fibres, from their arrangement, would seem to be capable of short-

[1] Kölliker, *op. cit.*, p. 328. These observations were made by Kölliker in 1855. In 1842, Goodsir described and figured an appearance on the free ends of the epithelium covering the villi, which he said was like a membrane covering the cells, though he did not distinctly assert the existence of such a membrane. (*On the Structure of the Intestinal Villi in Man and certain of the Mammalia, with some Observations on Digestion, and the Absorption of Chyle.—The Edinburgh New Philosophical Journal*, 1842, vol. xxxiii., p. 167.)

[2] Sappey, *Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., pp. 144, 145.

ening the villus, and this has actually been observed in specimens taken from the intestine shortly after death.

Fig. 2.



Intestinal villi, as seen by transmitted light. The villus, marked 1, has been partially withdrawn by contraction from its investing epithelium, which is thus left entire like the finger of a glove.—*a*, epithelium of the villus; *b*, granular matrix, or substances of the same. (BRINTON, *Cyclopædia of Anatomy and Physiology*, London, 1859, vol. v., supplement, p. 354.)

The anatomy of the lacteals as they originate in the villi has been the subject of much controversy; but almost all anatomists are now agreed that these vessels commence either by a plexus or by blind extremities, and have no direct openings into the intestinal cavity. The most generally received view at the present day is that the lacteals originate by a single delicate, nearly straight vessel in each villus; and that this vessel has no ramifications in the villus itself, but commences by a single, rather dilated, blind extremity near the apex.

Owing to the excessive tenuity of the walls of the lacteals in the villi—if indeed they exist at all—it has been found impossible to fill them with an artificial injection, though the lymphatics subjacent to them may be easily distended and studied in this way. Those who profess to have seen the single lacteal in the villus have done so by examining the parts when the lacteal system has been engorged with chyle. It seems, however, from a careful review of the whole subject, that the view entertained by Sappey is most nearly

correct. This observer, having tried all methods of artificial injection of the lacteals of the villi, came to the conclusion that nothing was to be learned from examinations of the mucous membrane after death. He then examined the villi of a dog in which the entire lacteal system was engorged with chyle, securing the chyle in the parts by ligatures applied to the principal trunks. When he examined the mucous membrane, he found it white, as though it had been sprinkled with milk, and the villi engorged and in a sort of erection. On placing some of these villi between two plates of glass and examining them with a magnifying power, he saw them divide, while under observation, into two portions; a peripheral portion, occupied by loops of blood-vessels, and a central, white portion, which had a cylindrical or ellipsoidal form. It is this central portion which has been taken for the single lacteal by most anatomists; but Sappey believes that this is an illusion; and that the white appearance is produced simply by the pressure of the glass forcing the chyle which is in the peripheral portion out of the villus, while the fluid is imprisoned in the central portion. The figures given by Kölliker certainly have the appearance described by Sappey; and if the lacteals really commence by a single dilated vessel, they have no analogue in other parts of the lymphatic system.

Sappey, while unable to demonstrate lacteals in the intestinal villi, infers their existence from analogy with the papillæ of various parts. The reason why they cannot be injected in the intestine is because the soft tissue in which they are embedded affords no support to their walls. As regards their mode of origin, we are disposed to adopt the opinion of Sappey, that they commence by a delicate anastamosing plexus situated outside the blood-vessels.[1] This is the way in which lymphatics have been shown to arise in the papillæ of the skin and other parts in which the density of the sur-

[1] SAPPEY, *op. cit.*, tome iii., p. 149 *et seq.*

rounding structures will admit of these vessels being filled with injection.

No satisfactory account has ever been given of nerves in the intestinal villi. If any exist in these structures, they probably are derived from the sympathetic system, which is largely distributed to the intestinal canal.

The solitary glands or follicles and the patches of Peyer,[1] or agminated glands, have one and the same structure; the only difference being that those called solitary are scattered singly in very variable numbers throughout the small and large intestine, while the agminated glands consist of numbers of these follicles collected into patches of different sizes. These patches are generally found in the ileum. The number of the solitary glands is so variable that it is impossible to give any general estimate of it. They are sometimes absent. The patches of Peyer are always situated in that portion of the intestine opposite the attachment of the mesentery. They are likewise variable in number, and are irregular in size. They are usually irregularly oval in form, and measure from half an inch to an inch and a half in length, by three-fourths of an inch in breadth. Sometimes they are three or four inches long, but the largest are always found in the lower part of the ileum. Their number is about twenty, and they are usually confined to the ileum; but when they are very numerous—for they sometimes exist to the number of sixty or eighty—they may be found in the jejunum, or even in the duodenum.

Two varieties of these patches have been lately described

[1] These patches, or collections of closed follicles in the intestine are generally called the patches or glands of Peyer, after the anatomist who described them, in 1677. It is admitted that Peyer was not their discoverer, as they had been observed by Séverin, Wepfer, and particularly by Grew, an English anatomist, in 1676; but the description by Peyer was so much more accurate and satisfactory than the observations of his predecessors, that the glands have since been called by his name. The work of Peyer is reprinted in the *Bibliotheca Anatomica*, by Clericus and Mangetus, tomus i., p. 150. This is entitled, *Exercitatio Anatomico-Medica Prima de Glandulis Intestinorum adjecta est Anatome Ventriculi Gallinacei.*

by anatomists. In one of these varieties, the patch is quite prominent, its surface being slightly raised above the general mucous surface, while in the other, the surface is smooth, and the patch is distinguished at first with some difficulty. The more prominent patches are covered with mucous membrane arranged in folds something like the convolutions on the surface of the brain. The valvulæ conniventes are arrested at or very near their borders. These are the only patches which are generally described as the glands of Peyer; the others, which may be called the smooth patches, being generally overlooked. The latter are covered with a smooth, thin, and closely adherent mucous membrane. Their follicles are small and numerous. The borders of these patches are much less strongly marked than those of the first variety. As they are evident only upon close examination, and as they are the only patches present in certain individuals, it is said that sometimes the patches of Peyer are entirely wanting. They are generally less numerous than the first variety, and, according to Sappey, are most abundant in persons of feeble constitution.[1] The villi are very large and prominent on the mucous membrane covering the first variety of Peyer's patches, especially at the summit of the folds. In the second variety, the villi are the same as over other parts of the mucous membrane, except that they are placed more irregularly and are not so numerous.

The intimate structure of these bodies has not been definitely settled in all its particulars. It is well determined, however, that the follicles which compose them are completely closed; the openings which have been said to exist being undoubtedly accidental ruptures made in preparing the specimen for microscopic examination. These follicles are somewhat pear-shaped, with their pointed projections directed toward the cavity of the intestine. Just above the follicle, there is generally a small opening in the mucous membrane, surrounded by a ring of intestinal tubules,

[1] SAPPEY, *op. cit.*, tome iii., p. 175.

and leading to a cavity, the base of which is convex and formed by the conical projection of the wall of the follicle. The diameter of the follicles is from $\frac{1}{72}$ to $\frac{1}{24}$ or even $\frac{1}{12}$ of an inch.[1] The small-sized follicles are generally covered by mucous membrane and have no opening leading to them. Each follicle consists of a rather strong capsule composed of an almost homogeneous, or very slightly fibrous membrane, enclosing a semi-fluid grayish substance, cells, blood-vessels, and probably lymphatics. The semi-fluid matter is of an albuminoid character. The cells are very small, rounded, and mingled with numerous small free nuclei. The blood-vessels have rather a peculiar arrangement. In the first place they are distributed between the follicles, so as to form a rich net-work surrounding each one. Numerous capillary branches are sent from these vessels into the interior of the follicle, returning in the form of loops. The obscurity in the anatomy of the follicles is chiefly with regard to the arrangement of their lymphatic vessels. These have not been distinctly traced within the investing membrane. They have been demonstrated surrounding the follicles, but it is still doubtful whether they exist in their interior. This question is so unsettled that it is impossible to make a definite statement on the subject. All that is known is that during digestion the number of lacteals coming from the Peyerian patches is greater than at other parts; but vessels containing a milky fluid are never seen within the follicles.

The mucous membrane covering the prominent patches is generally so thick and folded that the closed follicles cannot be seen from above and are only discernible from the under surface. In the smooth patches, the follices are generally well brought out by maceration in acetic acid.

The description of the follicles which compose the patches of Peyer answers, in general terms, for the solitary glands, except that the latter are found in both the small and large intestine.

[1] KÖLLIKER, *op. cit.*, p. 332.

Intestinal Juice.

Of the three fluids with which the food is brought in contact in the intestinal canal, namely, the bile, the pancreatic juice, and the intestinal juice, the last, the secretion of the mucous membrane of the intestine, presents the greatest difficulties in the investigation of its properties and function. If it be admissible to reason from the known mechanism of secretion in other parts, it is fair to suppose that the normal secretion from the mucous membrane of the intestine can only take place in obedience to the stimulus of food. The same cause induces the secretion of the pancreatic juice, and increases the flow of bile. As we have already seen, the food, as it passes from the stomach into the duodenum, is to a great extent disintegrated and mingled with the secretions from both the mouth and the stomach. Under these circumstances, it is evidently impossible, in the present state of the science, to collect the intestinal juice under perfectly physiological conditions, in a state of purity sufficient to allow of extended experiments regarding its composition, properties, and action in digestion. It is for these reasons that we cannot regard the observations of Frerichs and Bidder and Schmidt as, of themselves, throwing much light upon the properties and function of the fluid under consideration.

Frerichs attempted to collect the intestinal juice in the following way: He drew out from the abdomen of a living animal a loop of the small intestine, from four to eight inches in length, which was emptied, carefully cleaned by repeated washings with warm water, and isolated by two ligatures. The intestine was then returned to the abdominal cavity, the animal was killed after a few hours, and the contents of the isolated portion examined. These experiments were made upon dogs and cats, during the intervals of digestion. The fluid contained in the portion of intestine situated between the ligatures was found to be transparent, colorless, and viscid, with a strongly alkaline reaction. It

possessed, to a certain degree, the property of transforming starch into sugar, but the intensity of its action in this respect was very variable. It also imperfectly emulsified the fats and had some action upon the albuminoids. The general conclusion arrived at by Frerichs was that the intestinal juice was not very active in digestion.[1]

The method of studying the intestinal juice employed by Bidder and Schmidt more nearly fulfilled the necessary physiological conditions. They experimented upon dogs and cats, shutting off from the intestine the bile and pancreatic juice, and found that when starch was introduced into the canal it became transformed into sugar. They also observed that fat was emulsified to a considerable degree, and that albumen and meat were partially disintegrated and digested.[2] These observers were unable to collect the intestinal juice in quantity sufficient for analysis; and regarded the fluids which were obtained in quantity by Frerichs as the result of pathological action. That which they obtained was found to be colorless, very viscid, and strongly alkaline in its reaction.

As far as the composition and general properties of the intestinal juice are concerned, the observations of Colin upon horses are the most definite, though it is questionable whether he succeeded in obtaining the fluid in a normal state. To collect the fluid, an incision was made into the abdominal cavity, and from four and a half to six feet of the small intestine were drawn out. This portion was emptied by gently pressing with the finger from above downward, while with the other hand the upper portion was kept closed. Without removing the fingers, two soft clamps were then applied, thus shutting off the exposed part of the intestine from the rest of the canal. The gut was then returned and the wound in the abdomen closed. At the end of half an hour, the animal

[1] FRERICHS, *Verdauung*.—WAGNER'S *Handwörterbuch der Physiologie*, Braunschweig, 1846, Bd. iii., S. 832.

[2] BIDDER UND SCHMIDT, *Die Verdauungssäfte*, Leipzig, 1852, S. 270 *et seq.*

was killed by bleeding, and the contents of the isolated portion of the intestine were examined. The quantity of juice obtained was considerable, being from 1,235 to 1,852 grains for about six and a half feet of intestine. It was always found to be much less when intestinal digestion had been suspended, and its quantity could be increased by the injection into the loop of a little solution of manna, sulphate of soda, or aloes. The fluid thus obtained was clear, a little yellowish, with a saline taste and an alkaline reaction. It was mixed with mucus, which formed a sediment when the fluid was allowed to stand, and could be separated by filtration.[1]

Notwithstanding the care with which these observations were conducted, it is not probable that the fluid thus obtained by Colin was the normal intestinal juice; and it certainly does not correspond in its general characters with the fluids which have been studied by other experimenters.

It becomes an interesting question, in this connection, to determine whether the solitary and the agminated glands produce any secretion which is discharged into the intestinal cavity. Though these follicles are closed, the observations of Colin have shown pretty conclusively that they are capable of producing a secretion; but the precise mode of its formation is not so apparent. The experiment by which this was demonstrated was made on a pig, an animal in which there is an enormous agminate gland, ribbon-shaped, and over six feet in length. That portion of the ileum in which the gland is situated was emptied, and about four and a half feet of it isolated by two ligatures from the rest of the canal. At the end of an hour the animal was killed and the intestine examined. The surface of the gland was found covered with a layer of mucus, thicker and more consistent than over other portions of the membrane.[2] The only way in which it could reasonably be supposed that this secretion was produced is by

[1] Colin, *Traité de Physiologie Comparée*, Paris, 1854, tome i., p. 648 *et seq.*
[2] *Loc. cit.*

exhalation through the membranes of the follicles; as there is no evidence that their contents are discharged by rupture.

Taking only into consideration experiments upon animals, little definite information has been obtained concerning the composition and properties of the intestinal juice. We can readily see that this must be the case, since it has thus far been impossible, in observations of this kind, to fulfil the necessary physiological conditions. Further facts were evidently needed to harmonize the opposite results arrived at by different experimenters. It was the same in the progress of the physiology of stomach-digestion, which was unsettled and obscure until the normal gastric juice was obtained by Beaumont. The case of intestinal fistula reported by Busch, to which reference has already been made, has done much to elucidate this subject.[1]

The case referred to was that of a woman, thirty-one years of age, who, in the sixth month of her fourth pregnancy, was injured in the abdomen by being tossed by a bull. The wound was between the umbilicus and the pubes, presenting two contiguous openings connected with the intestinal canal. It was supposed that the openings were into the upper third of the small intestine. At the time the patient first came under observation, every thing that was taken into the stomach was discharged by the upper opening, and all attempts to establish a communication between the two by a surgical operation had failed. At this time the patient was extremely emaciated, had a voracious appetite, and was evidently suffering under defective nutrition resulting from the constant discharges of alimentary matter from the fistula. Having been treated, however, by the introduction of cooked alimentary substances into the opening connected with the lower

[1] BUSCH, *Beitrag zur Physiologie der Verdauungsorgane.*—VIRCHOW'S *Archiv*, Berlin, 1858, Bd. xiv., S. 140 *et seq.* An analysis of these observations, embracing most of the interesting points, is contained in the *American Journal of the Medical Sciences*, July, 1860, p. 217, and in the *North American Medico-Chirurgical Review*, of the same date.

end of the intestine, she soon improved in her nutrition, and was then made the subject of extended and interesting observations upon intestinal digestion.

With regard to the general properties of the intestinal juice, the observations of Busch upon this case agree with those of Bidder and Schmidt upon the lower animals. He never, in the natural condition, found a large quantity of secretion in the intestine. The fluid was white or of a pale rose-color, consistent, and always strongly alkaline. The maximum proportion of solid matter which it contained was 7·4 and the minimum 3·87 per cent.[1] The secretion could not apparently be obtained in sufficient quantity for ultimate analysis.

No better opportunity than this could be presented for studying the intestinal juice in its pure state. The nature of the case made it impossible that there should be any admixture of food, pancreatic juice, bile, or the secretion of the duodenal glands; and during the process of digestion, the lower part of the intestine undoubtedly produced a fluid of perfectly normal character. When we come to consider the action of the intestinal juice upon the various articles of food, our most reliable facts will be drawn from the observations made upon this case.

From what has been ascertained by experiments upon the lower animals and observations on the human subject, the intestinal juice has been shown to possess the following characters:

Its quantity in any portion of the mucous membrane which can be examined is small; but when the extent of the canal is considered, it is evident that the entire quantity of intestinal juice must be great, though beyond this, no reliable estimate can be made.

The intestinal juice is viscid, and has a tendency to ad-

[1] VIRCHOW'S *Archiv*, 1858, S. 156.

here to the mucous membrane. It is generally either colorless or of a faint rose tint, and its reaction is invariably alkaline.

With regard to the composition of the intestinal juice, little of a definite character has been learned. All that can be said is that its solid constituents exist in the proportion of about 5·47 parts per hundred.[1] In most analyses of fluids from the intestine, there is reason to believe that the normal intestinal juice was not obtained.[2]

The organs which secrete the fluid known as the intestinal juice are the follicles of Lieberkühn, the glands of Brunn, the solitary follicles, and the patches of Peyer. The fluid, however, is chiefly secreted by the follicles of Lieberkühn, which, as we have seen, exist in the mucous membrane of the intestine in immense numbers. Though the other organs mentioned do not contribute much to the secretion, they produce a certain quantity of fluid; and the intestinal juice must be regarded as a compound fluid, like the saliva, and not the product of a single variety of glands, like the gastric juice.

Action of the Intestinal Juice in Digestion.

The physiological action of the intestinal juice has been closely studied in the inferior animals by Frerichs and Bidder and Schmidt; but their experiments have been some-

[1] BUSCH, *loc. cit.*

[2] Colin (*op. cit.*, tome i., p. 649) gives the following analysis by Lassaigne of intestinal fluid taken from the horse. The mode in which this fluid was obtained by Colin has already been referred to. The fluid was collected in large quantity, and it seems probable, especially since the observations of Busch, that it was not the normal intestinal juice. Its specific gravity was 1,010 at 60° Fahr.

Water	98·10
Albumen	0·45
Chloride of sodium; " " potassium; Phosphate of soda; Carbonate of soda	1·45
	100·00

what contradictory. All observers, however, are agreed that this fluid is more or less active in transforming starch into sugar. But we must turn finally to the observations of Busch on the case of intestinal fistula in the human subject for the most satisfactory and definite information on this subject. In many points, it is true, these observations simply confirm those which have been made upon the inferior animals, but they are of great value, as they establish conclusively many important facts regarding the action of the intestinal juice in the human subject.

In this case, starch, both raw and hydrated, when introduced into the lower opening, where it came in contact only with the intestinal juice, was invariably changed into glucose. Cane-sugar was not transformed into glucose, but appeared in the fæces as cane-sugar. This is important, with reference both to the want of action of the intestinal juice upon cane-sugar, and the fact that cane-sugar, as such, is not absorbed in quantity by the intestinal mucous membrane.

Coagulated albumen and cooked meat were always more or less digested by the intestinal juice. This fact coincides with the observations of Bidder and Schmidt.

The observations which were made on fats, melted butter, and cod-liver oil, showed that the pure intestinal juice had little or no action upon them. These substances always appeared in the fæces unchanged. When, however, fatty matters were taken into the stomach, they were discharged from the upper opening in the intestine in the form of a very fine emulsion, and could not be recognized as fat.

It is evident from these facts that the intestinal juice is important in digestion, more as a fluid which aids the general process as it takes place in the small intestine, than as one which has a peculiar action upon any distinct class or classes of alimentary principles. It undoubtedly assists in completing the digestion of albuminoid substances and in transforming starch into sugar. Although, in the latter process, its action is very marked, the same property belongs

to the saliva and the pancreatic juice. Intimately mingled —as it always is during digestion—with the bile and the pancreatic juice, as well as with various alimentary substances, the intestinal juice should be studied as it operates upon the food, in connection with the other fluids found in the small intestine; the digestive action of all being most intimately associated.

CHAPTER XII.

PANCREATIC JUICE.

Pancreatic ducts—Mode of obtaining the pancreatic juice—General properties and composition of the pancreatic juice—Alterations of the pancreatic juice—Action of the pancreatic juice in digestion—Action upon fats—Destruction of the pancreas—Cases of fatty diarrhœa—Action of the pancreatic juice upon starchy and saccharine principles—Action upon nitrogenized principles—Summary of the functions of the pancreas in digestion.

THE physiological anatomy of the pancreas will not demand a very extended consideration, as most of the points of its descriptive anatomy have no direct relation to its physiology, and its minute anatomy belongs properly to the subject of secretion. The pancreas is a glandular organ, situated transversely in the upper part of the abdominal cavity, closely applied to its posterior wall. Its form is elongated, with an enlarged thick portion, called the head, which is attached to the duodenum, a body, and a pointed extremity, which is in close relation to the hilum of the spleen. Its average weight is from four to five ounces; its length is about seven inches; its greatest breadth about an inch and a half; and its thickness three-quarters of an inch.[1] It lies behind the peritoneum, which only covers its anterior surface.

According to Bernard, who has made numerous investigations into the anatomy of this gland, there are nearly always, in the human subject, two ducts opening into the

[1] HYDE SALTER, *Cyclopædia of Anatomy and Physiology*, London, 1859, vol. v., supplement, p. 83.

duodenum;[1] one which opens in common with the ductus communis choledochus, and one which opens about an inch above the main duct, called by Bernard the recurrent or accessory duct. The main duct is about an eighth of an inch in diameter, and extends along the body of the gland, becoming larger as it approaches the opening. The second duct is smaller, and becomes diminished in calibre as it nears the duodenum. Many anatomists describe but a single duct, regarding the other as anomalous. The dissections of Bernard, however, were very numerous, and show the almost constant occurrence of two ducts.[2]

In general appearance and minute structure, the pancreas is like the parotid and submaxillary glands. By the older anatomists it was known as the "abdominal salivary gland," on account of this resemblance in structure and an assumed similarity in the nature of their secretions. Recent developments in the physiology of the pancreatic juice have caused this name to be discarded.

It is only since it has been established by Bernard that one of the most important of the properties of the pancreatic juice is its power of emulsifying liquid fats, that the experiments of the older physiologists on the pancreas have assumed any great interest. In the elaborate work of Longet,[3] is a long quotation from Regnerus de Graaf, showing that this physiologist collected fluid from the pancreas in a living dog, in 1662. Following De Graaf, there were others who adopt-

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, p. 9. The fact of the almost constant existence of two pancreatic ducts in the human subject is now recognized by several anatomists. Sappey, out of sixteen dissections of the human pancreas, found, in one instance, a supplementary duct which had no communication with the duodenum, so that it was really in this case but a branch of the main duct. In all other instances, there were two ducts, as described by Bernard.—(*Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 248.)

[2] In dogs and in many other animals, two ducts exist; so that both must be ligated when it is desired to shut off the pancreatic secretion from the intestine.

[3] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 256.

ed the same method of experimentation. The operative procedure consisted simply in making an incision into the abdominal cavity, tying the intestine near the pylorus and a little distance below the opening of the pancreatic duct, opening the canal, and introducing a duck's quill into the orifice of the pancreatic duct. By arranging a little vial in such a position that fluid would drop into it from the quill, De Graaf collected in this way from a dog, two drachms, and even half an ounce of fluid in seven or eight hours. The fluid thus obtained was sometimes acid, very often acid and salt, and sometimes nearly insipid. Though, as has been so conclusively shown by Bernard, the experiment of De Graaf was nearly correct in principle, the fluid which he called pancreatic juice lacked the constant and necessary property of the normal secretion, namely, alkalinity.[1]

It is not necessary to detail the observations of all those who, since De Graaf, have obtained fluid purporting to be pancreatic juice. Most of the early observations on this subject were made with a view of proving either that the secretion of the pancreas was or was not identical with the saliva, and have no immediate bearing on our knowledge of the true function of this organ. Magendie repeated the experiment of De Graaf, but did not succeed in obtaining any fluid. He operated by simply exposing the orifice of the pancreatic duct and collecting with a pipette a few drops of liquid as it flowed. He obtained thus only a small quan-

[1] Regnerus de Graaf, *Tractatus Anatomico-Medicus de Succi Pancreatici Natura et Usu.* Lugd. Batavorum, Ex Officina Hackiana, 1671. In this curious and interesting treatise, which is quite elaborate, the anatomical characters of the pancreas are minutely described, the opinions of various authors concerning its uses are discussed, experiments to obtain the pancreatic juice are detailed with great care, and the properties of the fluid in health and disease are fully considered. The whole is illustrated with a number of excellent engravings. The process for obtaining the pancreatic juice so closely resembles that employed at the present day, that it is surprising that the normal fluid was not procured. Though De Graaf indicated very nearly the proper way to obtain pancreatic juice from a living animal, he developed little or nothing concerning its properties and functions.

tity, but enough to determine its alkaline reaction and its partial coagulability by heat.[1] In 1824, Leuret and Lassaigne obtained a considerable quantity of pancreatic juice from the horse, by incising the abdomen, exposing the ductus communis choledicus with the pancreatic duct, and introducing into the latter a gum-elastic tube, which was secured in place by a ligature. They found the fluid alkaline, and made an analysis of it, which is now quoted in many works on physiology. The digestive properties of the secretion were not observed.[2] Tiedemann and Gmelin obtained fluid from the pancreatic duct of a dog, by drawing out the duodenum and pancreas by an opening into the abdomen, and introducing into the duct a small glass tube. In this way they collected a little over one hundred and fifty grains in four hours. The first few grains of fluid were reddish and had an acid reaction. The greater part was clear and faintly alkaline, this reaction, however being attributed to a change in the secretion, owing to the sufferings of the animal.[3] These authors give no idea of the physiological properties of the fluid.

The above represents the state of the science concerning the function and properties of the pancreatic juice prior to 1846, when Bernard first made his experiments on this subject. Not only was the function of the pancreas unknown, but the ideas concerning the composition of the pancreatic juice were vague and uncertain and based upon contradictory observations. Bernard was the first to obtain normal pancreatic juice from a living animal and give a definite idea of its properties and functions; a fact which it is proper to particularly insist upon, inasmuch as since his discovery

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, 4me édition, tome ii., p. 470. An account of this observation is also given in a previous edition, which appeared in 1817.

[2] LEURET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 102 *et seq.*

[3] TIEDEMANN ET GMELIN, *Recherches Expérimentales Physiologiques et Chimiques sur la Digestion*, Paris, 1827, première partie, p. 27 *et seq.*

some have pretended that the facts which he established had been demonstrated before.[1] The following method for collecting the pancreatic juice from a living animal, one which we have repeatedly employed with success, is essentially that recommended by Bernard:

The animal generally employed by Bernard in these experiments is the dog. Selecting one of tolerably large size, he is secured to the operating table, and placed upon his left side. An incision from three to four inches in length is then made in the right hypochondrium, just below and parallel with the border of the last rib. The parts are first divided down to the fascia transversalis and the peritoneum. An opening is then made into the abdominal cavity about half the length of the incision through the skin and muscles; which brings to view the duodenum and a portion of the pancreas. The duodenum, with the pancreas attached to it, is then carefully drawn out of the abdomen. The next step is to introduce a small canula into the principal pancreatic duct. In the dog, there are always two pancreatic ducts: a small one, which opens into the intestine at or near the opening of the bile-duct, and a principal duct, which is situated about an inch below. To collect the juice, the tube should be introduced into the principal duct. This is found by turning the duodenum and pancreas so as to expose the posterior surface of the gland, when the duct, which is very short and almost concealed by the tissue of the pancreas, may be seen obliquely penetrating the intestinal wall. In the dog, the pancreas is composed of two portions; one, called the horizontal portion, which is attached to the duodenum, and a vertical portion, which passes away from the intestine between the folds of the mesentery. The duct is generally situated near the point where the pancreas ceases to be attached to the intestine. The tissue of the pancreas is to be carefully

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856.—*Leçons de Physiologie Expérimentale*, Paris, 1856.—*Leçons sur les Propriétés Physiologiques et les Altérations Pathologiques des Liquides de l'Organisme*, Paris, 1859.

pushed away from the duct with the end of the canula or the point of a knife, a small longitudinal slit is made in it with the scissors, and a silver canula about one twelfth of an inch in diameter and four inches in length is introduced and firmly secured in place by a ligature which has previously been thrown around the duct. The canula should be provided with a well-fitting stylet, with the point rounded so that it may be introduced into the duct with ease; and the end of the canula should be somewhat roughened, so that the ligature may secure it well in place. The canula will enter the duct for a short distance only, and it should not be introduced forcibly.

Fig. 8.

Full-grown shepherd-dog (female), in which a pancreatic fistula has been established.—A, silver tube to which a bladder has been attached;—B, bladder;—C, stopcock for the purpose of collecting the juice which accumulates in the bladder. (BERNARD *Leçons de physiologie expérimentale*, Paris, 1856, tome ii., p. 197.)

After this has been accomplished, the canula may be steadied by attaching it with a single stitch to the wall of the intestine. The stylet is now to be withdrawn and the parts carefully returned to the abdomen, leaving the end of the canula projecting at the anterior portion of the wound, which should now be carefully closed. Bernard recommends to first raise up the fascia and peritoneum with hooks and carefully attach their edges with sutures; and then to close, in the same way, the incision in the muscles and integument.

The animal may now be kept upon the table, and the fluid which is discharged from the tube collected in a test-tube, or a thin gum-elastic-bag may be attached. This may be provided with a stop-cock, so that the fluid may be drawn off at will.

Like the other digestive fluids, the pancreatic juice is only secreted in abundance during the process of digestion. It is therefore necessary to feed the animal moderately about an hour before the operation, so that the pancreas may be in full activity. When it is exposed at that time, it is filled with blood and has a rosy tint, contrasting strongly with its pale appearance during the intervals of digestion.

In performing the above experiment, it is generally better not to employ an anæsthetic agent, as this very frequently produces vomiting, arrests digestion for a time, and consequently interferes with the secretion of the pancreatic juice. This, however, is not always the case. We have sometimes performed the operation with the aid of ether and obtained a fair amount of fluid. It is also necessary to avoid traction upon the duodenum as much as possible, for this is almost sure to produce vomiting. To obtain the best results, the operation should be performed rapidly and with very little exposure of the pancreas. In some very successful experiments, Bernard has obtained from sixty to one hundred grains of juice in an hour, from a dog of medium size.[1]

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, pp. 46, 47.

Some of the most interesting facts developed by Bernard concerning the pancreatic juice relate to phenomena connected with its secretion. It is important to remember that the secretion of the pancreas is entirely suspended during the intervals of digestion. This fact has been definitely settled by Bernard,[1] and can easily be observed by opening animals in digestion and while fasting. In the first instance the pancreatic duct will be found full of normal secretion, and in the other, it will be almost, if not entirely, empty. Bernard has also found that the pancreatic juice begins to flow into the duodenum during the first periods of stomach-digestion, before alimentary matters have begun to pass in quantity into the intestine.

Another important fact determined by Bernard is that the secretion of the pancreas is readily modified by irritation and inflammation following the operation. When we come to treat of the general properties of the normal pancreatic fluid, it will be seen that its characteristics are, decided alkalinity, viscid consistence, and coagulability by heat. It is almost always the case that a few hours after the canula is fixed in the duct, the juice loses some of these characters and flows in abnormal quantity. With respect to susceptibility to irritation, the pancreas is peculiar; and its secretion is sometimes abnormal from the first moments of the experiment, especially if the operative procedure has been prolonged and difficult. That the properties above given are characteristic of the normal pancreatic secretion, there can be no doubt; as in all instances, fluid taken from the pancreatic duct of an animal suddenly killed while in full digestion is strongly alkaline, viscid, and coagulable by heat. This excessive sensitiveness of the pancreas has rendered fruitless all the attempts of Bernard to establish a permanent pancreatic fistula from which the normal juice could be collected.[2]

[1] *Op. cit.*, p. 43.

[2] A number of physiologists have attempted to establish a permanent com-

General Properties and Composition of the Pancreatic Juice.—In all the inferior animals from which the pancreatic secretion has been obtained in a normal condition, the fluid has been found to present pretty uniform characters. It is viscid, slightly opaline, and has a distinctly alkaline reaction. Bernard found the specific gravity of the fluid from the dog to be 1,040.[1] The quantity of organic matter which the normal secretion contains is very great, so that the fluid is completely solidified on the application of heat. This great coagulability is one of the properties by which the normal fluid may be distinguished from that which has undergone alteration.

Composition of the Pancreatic Juice of the Dog.[2]

Water	900 to	920
Organic matter precipitable by alcohol, and containing always a little lime (pancreatine)	90 to	73·60
Carbonate of soda, Chloride of sodium, Chloride of potassium, Phosphate of lime,	10 to	6·40
	1,000	1,000

Most of the analyses which have been made of the pancreatic fluid are not to be relied upon, as the manner in which

munication with the pancreatic duct. It is true that a fistula may be maintained in this situation for several days, but the fluid which is collected from it is usually abnormal. It is for this reason that some observations on the properties of the pancreatic juice, particularly those of the German physiologists, are opposed to those of Bernard ; for the fluids with which they operated were not the same. Colin (*Traité de Physiologie Comparée*, Paris, 1854, tome i., p. 633) has been to a certain extent successful in establishing fistulæ in animals of the bovine species. In one instance he made observations on the flow of the pancreatic juice in a young ox for six days. According to the observations of Colin, in all cases where a tube is introduced into the pancreatic duct, ulceration takes place at the site of the ligature and the tube falls out six or eight days after the operation.

[1] *Op. cit.*, p. 55.

[2] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, p. 60. The arrangement of this table has been altered from the original in order to make it correspond with the tables of the composition of the other digestive fluids.

the juice was obtained shows generally that it was not normal. There is no doubt, however, that the fluid which was obtained from the dog and analyzed by Bernard possessed all the characteristic physiological properties.

The chemical properties of the organic principle of the pancreatic juice are distinctive. Though, like albumen, it is coagulated by heat, the strong mineral acids, and absolute alcohol, it differs from albumen in the fact that its dried alcoholic precipitate can be redissolved in water, giving to the solution all the physiological properties of the normal pancreatic secretion. Bernard has also found that pancreatine is coagulated by an excess of sulphate of magnesia, which will coagulate caseine but has no effect upon albumen. It is important to recognize this distinction between pancreatine and other nitrogenized principles, especially albumen, from the fact that the last-named substance has the property of forming an emulsion with fats, though not so readily and completely as the pancreatic juice; and it is essential to decide whether the organic principle is a peculiar and distinct substance, or albumen transuded, pathologically perhaps, from the blood. There can be no doubt, in view of the marked chemical and physiological peculiarities of pancreatine, that this is a distinct proximate principle, characteristic of the pancreatic secretion and found in no other fluid.

Researches have likewise shown that pancreatine is the essential physiological constituent of the pancreatic juice, and the only one which gives this fluid its peculiar digestive properties. The contents of the duodenum, as the partly digested matters pass from the stomach, are generally acid; but this does not at all interfere with the action of the pancreatic juice. Though the secretion itself is alkaline, it retains its physiological properties when it has been rendered acid by admixture with gastric juice.[1]

The inorganic constituents of the pancreatic juice do not possess any great physiological interest, inasmuch as they do

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, p. 67.

not seem to be essential to its peculiar digestive properties. It has been shown, indeed, by Bernard, that the organic principle alone, extracted from the pancreatic juice and dissolved in water, is capable of imparting to the fluid all the physiological characters of the normal secretion.

The entire quantity of pancreatic juice secreted in the twenty-four hours has been variously estimated by different authors. After what has been said concerning the variations to which the secretion is subject, it is not surprising that these estimates should present great differences. Bernard was able to collect from a dog of medium size from eighty to one hundred grains in an hour;[1] but it must be remembered that only one of the ducts was operated upon, and that the gland is always very susceptible to irritation. There is no accurate basis for an estimate of the quantity of pancreatic fluid secreted in the twenty-four hours in the human subject, or of the quantity necessary for the digestion of a definite amount of food.

Unlike the gastric juice, the secretion of the pancreas, under ordinary conditions of heat and moisture, rapidly undergoes decomposition. In warm and stormy weather the alteration is marked in a few hours; but at a temperature of from 50° to 70° Fahr., it decomposes gradually in from two to three days. The changes which the fluid thus undergoes are interesting, from the fact that some physiologists, having experimented with an altered or an abnormal secretion, have failed to recognize certain of the characteristic properties of the normal fluid.[2] As it thus undergoes decomposition, the fluid acquires a very offensive putrefactive odor, and its coagulability diminishes, until finally it is not affected by heat. The alkalinity, however, increases in intensity; and

[1] *Loc. cit.*

[2] FRERICHS, in WAGNER'S *Handwörterbuch der Physiologie*, Braunschweig, 1846, Bd. iii., S. 848. It is stated by this author that the pancreatic juice does not emulsify fats more readily or completely than many other animal fluids. The juice which he used was undoubtedly abnormal, as it was not coagulable by heat.

when neutralized with an acid, there is a considerable evolution of carbonic acid; which does not occur in fresh pancreatic juice.

A reaction peculiar to decomposed pancreatic juice is described by Bernard. On the addition of a small quantity of chlorine-water, a red color is produced which disappears in an excess of the reagent.[1] The color is intense in proportion to the extent to which decomposition of the organic matter has advanced; except, however, when the process of putrefaction has arrived at its last degree, when the excessive alkalinity interferes with the reaction, and the color only appears when the fluid has been neutralized with an acid.[2]

Action of the Pancreatic Juice in Digestion.

It is only since the observations of Bernard, in 1848, that the pancreatic juice has been regarded as a fluid of any great importance in digestion. It has now been demonstrated, both by cases of disorganization of the pancreas in man, and by experiments on animals, in which the tissue of the organ has been destroyed, that the pancreatic juice is essential to digestion and to life; animals dying of inanition when its function has been abolished.

The most striking feature in the discovery made by Bernard was the action of the pancreatic juice in the digestion of fats; it being shown that these principles are acted upon almost exclusively by the pancreas; and that they pass through the alimentary canal undigested when this organ has been destroyed. For this reason, probably, the action of the pancreas in the digestion of fatty substances has received

[1] BERNARD, *op. cit.*, p. 57.

[2] This reaction with chlorine was observed by Tiedemann and Gmelin (*Recherches Expérimentales*, etc., Paris, 1827, tome i., p. 41); but these authors regarded it as one of the properties of the normal secretion. Bernard does not assume to have been the first to observe the peculiar color produced by chlorine, but simply to have pointed out the fact that it occurs in the decomposed, and not in the normal secretion.

an undue prominence; and its action upon other articles of food, though not at the present day overlooked, does not always receive proper consideration. We shall find that the pancreatic juice has an important action in the digestion of nearly all the alimentary principles as they pass out from the stomach.

Action upon Fats.—Even before the publication of Bernard's researches, it was pretty generally admitted that the digestion of fat consisted in its minute subdivision and suspension in the form of an emulsion. This view was adopted from the fact that during the absorption of fats from the intestinal canal, the lacteals and thoracic duct always contain innumerable small fatty globules; but the ideas of physiologists as to the particular fluid by which the emulsification of fats is accomplished were not very well settled. The most generally received opinion, however, was that this was effected by the bile; but experiments on this subject were very contradictory. The observations of Brodie, confirmed by Mayo,[1] seemed to show that ligation of the bile-duct prevented the formation of white chyle; while the experiments of Magendie led to a precisely opposite conclusion.[2]

Eberle, the author of a treatise on digestion published in 1834,[3] who, it will be remembered, prepared an artificial gastric juice by macerating in water the mucous membrane of the stomach,[4] adopted the same method in preparing an artificial pancreatic fluid. He made a number of experiments with a fluid prepared by infusing finely divided portions of the pancreas of the ox in pure water. The results of his experiments with this fluid upon the fats foreshadowed the discovery of Bernard, though they cannot justly

[1] MAYO, *Outlines of Human Physiology*, London, 1827, p. 406.

[2] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 118.

[3] EBERLE, *Physiologie der Verdauung*, Würtsburg, 1838. Longet and Milne-Edwards refer to an edition of this work bearing the date 1834. The edition of 1838 is apparently nothing more than a reprint.

[4] See page 236.

be said to have anticipated it. The following is the experiment described by Eberle: "Artificial pancreatic fluid was mixed and shaken up with a drop of oil, and presently assumed the appearance of an emulsion, but after repose several small oil-drops again presented themselves, which appeared to have lost little or none of their clearness and transparency. However, when more oil was added, and the mixture shaken, receiving the warmth of the hand, it then became an opaque, yellowish-white fluid, from which, after repose, considerable oil separated on the surface. But this oil was itself white and opaque, and so finely subdivided, that it presented a creamy appearance, and the remaining fluid did not again become clear.

"Consequently the pancreatic juice is capable of taking up fat in a very finely subdivided condition and thus forming a sort of emulsion."[1]

The opinion thus advanced by Eberle was a mere conjecture, based upon the behavior of an artificial fluid which had not been proven to possess the properties of the normal pancreatic secretion. Though these passages are quoted by Longet[2] as proof that Bernard did not discover the function of the pancreas, it must be acknowledged that they bear no more relation to the discovery as established by positive demonstration, than do the sayings of Servetus, Columbo, or Cesalpinus, to the demonstration of the circulation of the blood by Harvey. Eberle did not obtain the secretion of the pancreas, and the emulsion which he formed with his artificial fluid was manifestly very imperfect. Furthermore, the experimental basis for his views was so slight that his observations are not even mentioned in the works on physiology published at that time, save in one, where they received merely a passing allusion.[3] It is only since the function of the pancreas has been

[1] EBERLE, *op. cit.*, p. 251.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 260.

[3] LONGET (*loc. cit.*) states that the opinion of Eberle seems to have been adopted by Burdach. Burdach was the author of a large work on physiology, in

demonstrated by Bernard, and his observations have been so widely corroborated that it is now regarded as an established fact, that earlier publications on this subject have possessed any interest or importance.

With the exception of the above-mentioned observations of Eberle, nothing definite had been ascertained concerning the digestion of fats anterior to the experiments of Bernard.[1]

One of the most remarkable facts observed by Bernard was that, in the rabbit, after the ingestion of fatty matters, vessels filled with white chyle do not make their appearance

nine volumes, with additions by E. Burdach, Dieffenbach, Mayer, J. Müller, Rathke, Siebold, Valentin, and Wagner.—(*Traité de Physiologie considérée comme Science d'Observation*, trad. par Jourdan, Paris, 1837-1841.) This work is mainly a compilation of the physiological literature of the day, drawn largely from the German. In vol. ix., p. 380, which is referred to by Longet, Burdach quotes two lines from Eberle, saying that "according to Eberle, it (the pancreatic juice) serves besides to dilute the fat, and to reduçe it to the form of an emulsion; a great part of its constituent principles pass also into the chyle." But in the previous page (379) he has the following paragraph:

"We have even less knowledge of the effects of the pancreatic juice than of those of the bile. Eberle supposes that it is analogous to the intestinal juice, because the pancreas is a continuation of the intestine. But, in reasoning in this manner, one would have fully as much foundation for saying the same thing of the bile. And when Eberle attributes to it the effects which he has remarked in the pancreatic juice artificially imitated, by that, he gives a very feeble basis to his theory, which fortunately contains nothing in particular."

As the above constitutes about the only mention which is made of the observations of Eberle, even in German works, it is very easy to appreciate the state of knowledge concerning the function of the pancreas, anterior to the experiments of Bernard; and it is not surprising that he should have been ignorant of these experiments, which have been only quoted since his discovery has taken so prominent a place in science.

[1] These experiments were commenced in the winter of 1846, and were first publicly announced in the year 1848, in a communication to the Society of Biology of Paris. They were subsequently made the subject of a memoir which received the prize of the Academy of Sciences, in 1850. A full account of all the researches of Bernard upon this subject is contained in his *Mémoire sur le Pancréas*, Paris, 1856. The results of his experiments are also contained in his *Leçons sur la Physiologie Expérimentale*, Paris, 1856, and in the *Leçons sur les Propriétés Physiologiques et les Altérations Pathologiques des Liquides de l'Organisme*, Paris, 1859, tome ii.

at the commencement of the small intestine, as in other animals, but are first seen from twelve to twenty inches below the pylorus. The anatomical peculiarity in these animals is that the pancreatic duct, instead of opening into the intestine with the bile-duct at the upper part of the small intestine, has its opening from twelve or twenty inches below; just at the point where the chyliferous vessels are observed. This fact, which we have frequently confirmed, points directly to the pancreatic juice as the agent principally, if not exclusively, concerned in emulsifying the fats; while it shows that the bile possesses little or no immediate efficiency in this regard.

Following out this line of inquiry, and operating with fresh, coagulable pancreatic juice and the liquid fats, or those capable of being liquefied by gentle heat, it was found that slight agitation of this fluid with the fats produced a very fine and permanent emulsion, similar in every respect to the milky fluid found in the lacteals during digestion. In fact, comparative analyses of the lymph and chyle have shown that the latter liquid is nothing more than lymph, with the addition of fatty emulsion. As soon as the absorption of fat is completed, the lacteal vessels lose their opaque white contents, and carry nothing but colorless lymph. This is one of the great experimental facts upon which is based the view that the pancreatic juice has the property of digesting the fats. Concerning the accuracy of this observation there can be no doubt. The fact has been so frequently confirmed, that it must now be considered as established beyond question; and we can add our testimony to its accuracy from personal observation. It is true that some of the German physiologists have been unable to confirm these experiments;[1] but by carefully following out the process indicated by Bernard, which is detailed with great care, we have invariably found his observations to be correct. It

[1] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 506 *et seq.*

is well known that many of the German experimenters operated with pancreatic juice which was not coagulable, and which Bernard regards as abnormal and incapable of digesting fat. With regard to the observation upon the lacteals of the rabbit, by following out carefully the directions given by Bernard, and injecting into the upper part of the intestine of this animal a small quantity of a solution of fat in ether, we have seen the lacteals appear just at the orifice of the pancreatic duct and below it, while they were absent above.[1]

The pancreatic juice is the only one of the digestive fluids which is capable of forming a complete and permanent emulsion with fats. The fact that the other digestive fluids will not accomplish this is easily demonstrated as regards saliva, gastric juice, and bile. The intestinal juice is then the only one which might be supposed to have this property. The observations of Busch on this point, in his case of intestinal fistula, are conclusive. He found that fatty matters taken into the stomach were discharged from the upper opening in the intestine in the form of a fine emulsion, and were never recognizable as oil; but that fat introduced into the lower intestinal opening was not acted upon, and was discharged unchanged in the fæces.[2]

Another peculiarity noted by Bernard in the emulsion resulting from the action of pancreatic juice upon fats is that it persists when diluted with water, and will pass through a

[1] It has been shown by Bernard that ether is one of the most powerful excitants of the pancreatic secretion; and consequently when fat in solution in ether is introduced into the intestinal canal, the secretion is poured out in abundance, and the fat is immediately emulsified.—(*Leçons sur les Effets des Substances Toxiques et Médicamenteuses*, Paris, 1857, pp. 417, 418.)

The observations of Bernard upon rabbits were fully confirmed in a series of experiments performed under the direction of Prof. Samuel Jackson, of Philadelphia. He fed these animals with fat and vegetables in the way indicated by Bernard, and never saw the lacteals fully injected with chyle above the opening of the pancreatic duct.—(*American Journal of the Medical Sciences*, October, 1854.)

[2] Busch, in Virchow's *Archiv*, Berlin, 1858, Bd. xiv., S. 165, 175; and *American Journal of the Medical Sciences*, July, 1860, pp. 219, 220.

moistened filter like milk. This does not take place in the imperfect emulsion formed by a mixture of oil with any other of the digestive fluids.

Although the normal pancreatic juice is constantly alkaline, this is not an indispensable condition as regards its peculiar action upon fats; for the emulsion is none the less complete when the fluid has been previously neutralized with gastric juice.

Bernard has shown that the pancreatic juice and the tissue of the pancreas have the property of saponifying fats, or decomposing them into a fatty acid and glycerine, and that this property is not possessed by any other tissue or liquid of the economy.[1] The question naturally arises, then, whether this be an accidental property of the tissue and the secretion of the pancreas, or whether partial saponification of fat takes place in digestion. Concerning this point there is no difference of opinion among physiological chemists. The fat which is contained in the lacteal vessels is always neutral; and the absence of any fatty acid has been recognized by Bernard, as well as by others. The inevitable conclusion to be drawn from this fact is, that while fat may be in part decomposed into an acid and glycerine by the pancreatic juice, out of the body, in the natural process of digestion, either this does not take place, or the acid is not absorbed by the lacteals. The greatest part, if not the whole, of the fat which is digested in the small intestine is simply formed into an emulsion by the pancreatic juice, and undergoes no chemical alteration.

To complete the experimental evidence of the action of the pancreatic juice in the digestion of fats, Bernard attempted to extirpate or destroy the pancreas in a living animal. This he found very difficult. All attempts to extirpate the organ with the knife being unsuccessful, the injection of foreign matters into the duct was resorted to. After a great number of unsuccessful experiments, in two in-

[1] BERNARD, *op. cit.*, p. 94 *et seq.*

stances, the functions of the gland were suspended for a time, and its tissue was partly destroyed by the injection of melted tallow. In both of these observations, the effects upon digestion were very marked. Though the appetite was voracious, the animals became gradually emaciated, and the fæces contained a large quantity of rancid undigested fat. At the same time, other alimentary principles, incompletely digested, were recognized in the discharges. In two dogs operated upon by Bernard, in which the experiments were successful, the nutrition and the alvine discharges became normal at the thirteenth and the seventeenth day. After the animals had completely recovered, they were killed, and the pancreas in both instances was found partially destroyed.[1]

Now that the action of the pancreatic juice upon fats is so well understood, it is a matter of surprise that the cases of fatty diarrhœa connected with disorganization of the pancreas, which were reported by Dr. Richard Bright, in 1832,[2] did not direct the attention of physiologists to the function of this organ. These cases, with others of a similar character which have been reported from time to time, are now brought forward as strong evidence of the action of the pancreas in the digestion of fats. Many of them presented a train of symptoms analogous to those observed in animals after partial destruction of the gland. The presence of fat in the alvine dejections was most marked; and, as is now well known, this could be nothing but the undigested fatty principles of the food. In the three cases observed by Bright, the pancreas was found so disorganized that its secreting function must have been almost, if not entirely, abolished.

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, pp. 17 and 69.

[2] BRIGHT, *Cases and Observations connected with Diseases of the Pancreas and Duodenum.—Medico-Chirurgical Transactions*, London, 1833, vol. xviii., p. 1 *et seq.* In the same volume (p. 57) is a case of jaundice with discharge of fatty matter from the bowels and a contracted state of the duodenum, reported by E. A. Lloyd, Esq., and still another case of the same character is reported by Dr. J. Elliotson.

In the case reported by Mr. Lloyd, the condition was the same; and in the case reported by Dr. Elliotson, "the pancreatic duct and the larger lateral branches were filled with white calculi." Another interesting case of disease of the pancreas is detailed in the catalogue of the Anatomical Museum of the Boston Society for Medical Improvement, 1847. In this case it was observed by the patient that fatty discharges from the bowels did not take place unless fatty articles of food had been taken. After death, a large tumor was found in the situation of the pancreas, but all trace of the normal structure of the organ had been destroyed.[1]

Many more cases of this character are quoted by Bernard and others, and they fully confirm the observations and experiments which have been made upon the lower animals.[2] They all seem to show that the function of the pancreas in digestion is essential to life, but that one of the chief disorders in digestion incident to the destruction of this gland relates to the digestion of fats.

Taking into consideration all the facts bearing upon this subject, the conclusion is inevitable that the chief agent in the digestion of fats is the pancreatic juice; and that this fluid acts by forming with the fat a very fine emulsion, thus reducing it to a form in which it can be absorbed. How far the bile may assist in this process is a question which will come up for consideration hereafter; but the facts with regard to the pancreatic juice are conclusive. In making this unqualified statement, it is not intended to ignore the experiments of some of the German physiologists, which have

[1] *A Descriptive Catalogue of the Anatomical Museum of the Boston Society for Medical Improvement*, Boston, 1847, p. 174.

[2] Dr. John H. Griscom, of New York, gives the details of an interesting case of Diarrhœa Adiposa, in the *Transactions of the American Medical Association*, 1813, volume xiv., p. 173 *et seq.* In this case, recovery apparently took place, and the patient passed from observation. He also gives a tabulated analysis of twenty-five cases of discharge of fatty matter from the bowels observed by various authors. It is not unusual for cases of this kind to terminate in recovery.

seemed opposed to the observations of Bernard.[1] To many of these experiments, reference has already been made. In endeavoring to ascertain the truth of an important physiological statement supported by experimental facts, it is indispensable first to put one's self in the position of the experimenter, and carefully to repeat his observations in precisely the way in which they were originally made. Having done this, we have been able on many occasions to confirm the most important of the experiments of Bernard;[2] and we can find nothing in the contradictory observations of others which invalidate their accuracy. So long as physiologists operate with the watery secretion which flows from a permanent pancreatic fistula, they will fail to observe the properties of the normal fluid; and if they will carefully follow the experimental procedure so minutely detailed by Bernard, their observations will be in accordance with the results at which he has arrived.

Action upon Starchy and Saccharine Principles.—All physiologists are agreed with regard to the action of the pancreatic juice in transforming starch into sugar. This was first observed, in 1844, by Valentin, who experimented with an artificial fluid made by infusing pieces of the pancreas in water.[3] Bouchardat and Sandras first noted this property in the normal pancreatic secretion. They obtained the secretion in small quantity from the goose, by killing it while

[1] FRERICHS, *Die Verdauung*, in WAGNER'S *Handwörterbuch der Physiologie*, Braunschweig, Bd. iii.—LENZ, *De Adipis Concoctione et Absorptione*, Dorpati, 1850.—BIDDER UND SCHMIDT, *Die Verdauungssäfte*, Leipsig, 1852.—LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i.

[2] We have repeatedly confirmed most of the experiments of Bernard showing the action of the pancreatic juice upon fats; but have not succeeded in destroying the pancreas in a living animal and noting the effects upon digestion of the absence of the secretion. We attempted this a number of times, in 1860, by injecting the pancreatic duct with fat, but in all of the experiments the animals died of peritonitis.

[3] VALENTIN, *Lehrbuch der Physiologie des Menschen*, Braunschweig, 1844, and second edition, 1847, Bd. i., S. 356.

in full digestion and pressing out by the duct all the fluid which the pancreas contained. They noted also the viscid character of the secretion and its alkaline reaction.[1] All who have experimented on the pancreatic juice since this time have confirmed these observations.[2]

The property of converting starch into sugar is possessed by several of the digestive fluids. We have seen that the starchy elements of food are acted upon by the saliva, that this action is not necessarily arrested as these principles, mixed with the saliva, pass into the stomach, and that the intestinal juice of itself is capable of effecting the transformation of starch into sugar to a considerable extent. It therefore becomes an important question to determine precisely how far the pancreas is actually concerned in the digestion of this class of principles.

Bernard places the pancreatic juice at the head of the list of the digestive fluids which act upon starch.[3] This view is undoubtedly correct; though he goes a little too far in claiming that starch is almost exclusively digested by the pancreas. Bernard's experiments, however, were made chiefly on dogs; and these animals do not naturally take starch as food.[4] In man, some of the starchy principles of the food are acted upon by the saliva, but undoubtedly, most of the starch

[1] BOUCHARDAT ET SANDRAS, *Des Fonctions du Pancréas et de son Influence dans la Digestion des Féculents.—Mémoire adressé à l'Académie des Sciences, le 14 avril*, 1845,—*Supplément à l'Annuaire de Thérapeutique*, Paris, 1846, p. 148 *et seq.*

[2] Frerichs, Bidder and Schmidt, Bernard, Lehmann, and all to whom we have referred in connection with the function of the pancreas, are agreed with regard to its action upon starch.

[3] *Op. cit.*, p. 128.

[4] Bernard found that in pigeons, the pancreas could be extirpated without producing immediate death. In a pigeon from which the pancreas had been removed by tearing the tissue away piecemeal with the forceps, when the animal commenced to eat, two days after the operation, vegetable cells containing unaltered starch were found in abundance in the fæces; while, in health, the starch which these cells contained was always dissolved out (*Leçons de Physiologie Expérimentale*, Paris, 1856, p. 330).

taken as food is digested in the small intestine. Though the intestinal juice is capable of effecting its transformation into sugar, the experimental evidence is conclusive that in this it is subordinate to the pancreatic juice, which latter effects this transformation, at the temperature of the body, with extraordinary activity. There is no evidence that the bile has any thing to do with this action; and, indeed, it is stated by Lehmann, that starch is not materially affected by the bile, even after prolonged digestion.[1]

To sum up the whole process of the digestion of starch, it may be stated, in general terms, that this principle, when hydrated, which is the usual condition in which it is taken into the stomach of the human subject, is slightly acted upon by the saliva, both in the mouth and after it has passed into the stomach; when it is taken raw, it is hydrated in the stomach, and usually undergoes no transformation into sugar until it has passed into the small intestine; and when it passes out at the pylorus, mainly by the action of the pancreatic juice but with the assistance of the intestinal juice, it is transformed into glucose, and in this form is absorbed.

We have already followed out the digestion of sugar as far as the small intestine.[2] Glucose undergoes no change in the stomach, and is taken directly into the circulation. It is probable, also, from the experiments of Bouchardat and Sandras and others, that a small quantity of cane-sugar may in like manner be taken up by the blood-vessels of the intestinal mucous membrane.[3] It has been shown that a small quantity of cane-sugar is transformed into glucose in the stomach, but, as we noted in treating of stomach-digestion, the quantity is inconsiderable, and the transformation depends simply upon the presence of a free acid in the gastric juice.

[1] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 492.

[2] See page 268.

[3] BOUCHARDAT ET SANDRAS, *De la Digestion des Matières Féculentes et Sucrées, etc.—Supplément à l'Annuaire de Thérapeutique*, Paris, 1846, p. 81 *et seq.*

As most of the saccharine principles of food exist in the form of cane-sugar, it is the action of the digestive fluids upon this variety of sugar which possesses the greatest physiological interest. As cane-sugar passes from the stomach into the duodenum, it is almost instantly transformed into glucose. This fact has lately received additional confirmation in the case of intestinal fistula observed by Busch. In this case, when cane-sugar was introduced in quantity into the stomach, fasting, the fluid which escaped from the upper end of the intestine contained a small quantity of glucose, but never any cane-sugar.[1]

It now becomes a question whether this transformation into glucose is effected by the bile, the intestinal juice, or the pancreatic juice. The pancreatic juice and the intestinal juice are the two fluids which might be supposed to have this effect; as it has been repeatedly demonstrated that the bile has of itself no direct action upon any of the alimentary principles.

This point is settled by the experiments of Busch upon the lower end of the intestine, in his case of fistula. Matters introduced into this lower opening came in contact with the intestinal juice only. He found that cane-sugar, exposed thus to the action of the intestinal juice, was not converted into glucose, but a large portion of it was found in the fæces. These observations also indicate that cane-sugar is not readily absorbed by the intestinal mucous membrane until it has been transformed into glucose.

Out of the body, the pancreatic juice is capable, if kept but for a short time in contact with any of the saccharine principles, of transforming them into lactic acid. Bouchardat and Sandras believed that sugar was always changed into lactic acid in digestion;[2] but further experiments have shown that this is not the case.[3] The contents of the small intestine are sometimes alkaline or neutral, and sometimes

[1] *Loc. cit.* [2] *Loc. cit.*

[3] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, p. 133.

acid. When a very large quantity of sugar has been taken, a part of it may be converted in the intestine into lactic acid, and this may happen with the sugar which results from the digestion of starch; but under ordinary conditions, starch and cane-sugar are readily changed into glucose and are absorbed without undergoing further transformation. All the varieties of sugar after they have been absorbed by the portal vein and carried to the liver, are here transformed into glucose, the only form under which they can be used in nutrition.

Action of the Pancreatic Juice on Nitrogenized Principles.—Although Eberle and some other German observers, particularly Purkinje and Pappenheim, alluded to the action of an acid infusion of the tissue of the pancreas upon certain nitrogenized principles, as early as 1834 and 1836, it is only since the normal pancreatic juice was obtained by Bernard that any thing definite has been ascertained concerning its action upon this class of alimentary substances;[1] and even now, much remains to be done in this direction.

We have frequently had occasion to insist upon the great relative importance of intestinal digestion, and it has been apparent that in the stomach, the process of disintegration of food is not final, even as regards many of the nitrogenized principles, but is rather preparatory to the complete liquefaction of these principles, which takes place in the small intestine. The experiments, already referred to, of Bernard, in which the pancreas has been partly destroyed in dogs, show

[1] The ideas of the German physiologists concerning the functions of the pancreas were very indefinite before the publication of Bernard's experiments. The vague and uncertain observations of Eberle and of Purkinje and Pappenheim are simply alluded to in some of their most elaborate works upon physiology (see BURDACH, *Traité de Physiologie*, trad. par Jourdan, Paris, 1841, tome ix., p. 317). These observations by no means justify the claim made by Corvisart that the authors referred to discovered the action of the pancreatic juice upon the albuminoids (CORVISART, *Sur une Fonction peu connue du Pancréas*, Paris, 1857 -1858, p. 1).

rapid emaciation, with great voracity, and the passage, not only of unchanged fats and starch, but of undigested nitrogenized matter in the dejections. In some instances, pieces of tripe which had been fed to the animal were recognizable in the fæces "by their aspect, because of their slight alteration."[1] The voracious appetite, progressive emaciation, and the passage of all classes of alimentary substances in the fæces, after this operation, demonstrate conclusively the great importance of the pancreatic juice in digestion. But when we inquire into the precise mode of action of this fluid upon the albuminoids, the question becomes one of great difficulty. If the bile be shut off from the intestine and discharged externally by a fistulous opening, the same voracity and emaciation are observed; and yet there is no single alimentary substance upon which the bile, of itself, can be shown to exert a decided digestive action. Furthermore, the pancreatic juice is evidently calculated to act upon alimentary principles after they have been subjected to the action of the stomach, a preparation which is absolutely essential to proper intestinal digestion; and once passed into the intestine, the food comes in contact with a mixture of pancreatic juice, intestinal juice, and bile. We have to study, therefore, the special action of the pancreatic secretion upon the albuminoids, as far as it can be isolated, and its action in conjunction with the other intestinal fluids, and in the presence of other alimentary principles in process of digestion.

The first definite observations upon these points were made by Bernard. He found that the albuminoid substances generally, exposed to the action of the pancreatic juice out of the body, became rapidly softened and dissolved in some of their parts, but soon passed to a condition of putrefaction. An analogous change, it will be remembered, also takes place in starchy and fatty matters when exposed to the action of the pancreatic juice out of the body, and they pass through the various stages of transformation respectively into lactic

[1] BERNARD, *Mémoire sur le Pancréas*, Paris, 1856, p. 137.

acid and the fatty acids. This putrefactive action does not take place in albuminoids which have been precipitated after having been cooked, nor in raw gluten or caseine. The presence of fat also interferes with putrefaction; so that Bernard concludes that the fats have an important influence in the intestinal digestion of nitrogenized principles.[1] The observations of Corvisart, who experimented, however, with an artificial fluid formed by infusing the fresh pancreas in water, were made in order to prove the great activity of the pancreatic juice in the digestion of albuminoid substances. Though these experiments are frequently referred to as throwing considerable light upon a function of the pancreas but little known, the author of them does not seem, in their execution, to have fulfilled the necessary physiological conditions; and his results cannot, therefore, be accepted as definite and conclusive.[2]

Taking into consideration what has been positively ascertained concerning the action of the pancreatic juice upon the

[1] *Op. cit.*, pp. 129 and 130.

[2] CORVISART, *Sur une Fonction peu connue du Pancréas*, Paris, 1857–1858, and *Collection de Mémoires sur une Fonction peu connue du Pancréas*, Paris, 1857–1863. In the experiments upon the digestion of albuminoids in the duodenum of a living animal, the intestine was exposed, the duodenum washed out with a stream of tepid water, and albumen or some other substance introduced; the duodenum being isolated from the rest of the intestine by two ligatures. That normal digestion and absorption can take place under these conditions is not conceivable. Again, in experimenting upon the action of the pancreatic juice out of the body, the pancreatic secretion is never used, but an infusion of the tissue of the gland is substituted. Though something may be learned by experimenting in this way, results thus obtained should be compared with those which are obtained by using the actual secretion of the gland. By using all the precautions recommended by Corvisart in a paper published in reply to certain objections made to his experiments, by Dr. Brinton (*Journal de la Physiologie*, Paris, 1860, tome iii., p. 473 *et seq.*), we have never been able to manufacture a pancreatic juice with which we could demonstrate to a medical class the characteristic properties of the normal secretion. Corvisart does not seem to have verified any of his observations by operating with the actual secretion of the pancreas; and, on the other hand, has written several memoirs to show that infusions of the tissue of glands resemble the natural secretions more closely than the fluids obtained from their ducts.

albuminoids, there can be no doubt with regard to the importance of its function in the digestion of these principles after they have been exposed to the action of the gastric juice. The experiments of Bernard and the later observations of Dalton upon the digestion of these substances after they have passed out of the stomach show that they undergo important and essential changes as they pass down the intestinal canal. While the bile and the intestinal juice are by no means inert, they seem to be only auxiliary in their action to the pancreatic juice. When meat is taken into the stomach, or is exposed even for a long period to the action of the gastric juice, there is always more or less insoluble residue, which can be shown by microscopical examination to consist of the muscular substance. Dalton has shown, in a carefully conducted series of observations, that the characteristic striæ gradually disappear and the tissue is dissolved as it passes down the intestine;[1] and although he entertains the view that this is due to the action of the gastric juice which is continued in the intestine, the evidence derived from the observations of others seems to show that it depends mainly upon the pancreatic juice.

The preparation which the albuminoids undergo in the stomach is undoubtedly necessary to the easy digestion, in the small intestine, of that portion which is not dissolved by the gastric juice. This fact has been conclusively demonstrated by experiments on intestinal digestion in the inferior animals, and by the observations of Busch in the case of intestinal fistula in the human subject.

Summary.—The action of the pancreas upon the various articles of food may be summed up in a few words:

This fluid is the only one capable of forming an instantaneous, complete, and permanent emulsion with the liquid fats, thus preparing them for absorption by the lacteals. The fat from the adipose tissue is set free in the stomach and

[1] DALTON, *Treatise on Human Physiology*, Philadelphia, 1864, p. 157 *et seq.*

liquefied, but is not otherwise acted upon. In normal digestion, the pancreatic juice does not acidify fats.

Raw starch—which becomes hydrated in the stomach—and cooked starch are changed into sugar by the pancreatic juice, and in this form are absorbed. In this the pancreatic secretion is aided by the intestinal juice, a fluid which possesses the same property, though in a less degree. Cane-sugar and milk-sugar are probably changed into glucose by the pancreatic juice alone. This change takes place to a very slight extent in the stomach.

The albuminoids, such as gluten, fibrin, albumen, caseine, and musculine, which have been disintegrated but not dissolved by the gastric juice as they pass out of the stomach, are liquefied by the pancreatic juice with the aid of the bile and the intestinal juice, are changed into albuminose, or peptones, and are thus absorbed. This takes place whether the reaction of the contents of the intestine be alkaline, acid, or neutral. Though the action of the pancreatic juice, out of the body, soon induces putrefaction in many of the albuminoids, this does not occur in the natural process of digestion. The presence of a small quantity of fat retards this putrefactive change in artificial digestion, and it may have some influence upon the digestion of these principles in the intestine.

As the different articles pass out at the pylorus, in the natural process of digestion, they are in the condition most favorable for the action of the intestinal fluids. The starch is always hydrated, with the particles separated and distributed through the entire mass of food; the oil is freed from the vesicles in which it is enclosed in the adipose tissue, and is likewise distributed through the alimentary mass; the nitrogenized articles are disintegrated, softened, and reduced to a pultaceous mass; and, in fine, all the food which has not been digested in the stomach is prepared to absorb with avidity the fluids which it meets in the intestine, so that it rapidly undergoes the final changes which take place in this part of the digestive apparatus. Again, the food is passed

out very gradually, and only after it has been fully prepared in the stomach for intestinal digestion.

In intestinal digestion, all the secretions found in the small intestine combine to accomplish the final result; and it only remains for us to examine how far and in what way this process is influenced by the bile.

CHAPTER XIII.

ACTION OF THE BILE IN DIGESTION—MOVEMENTS OF THE SMALL INTESTINE.

Question of the excrementitious or recrementitious character of the bile—Ligation of the ductus communis choledochus—Biliary fistula—General constitution of the bile—Observations on a dog with biliary fistula—Variations of the bile with digestion—Movements of the small intestine—Peristaltic and antiperistaltic movements—Cause of the movements of the small intestine—Function of the gases in the small intestine—Peristaltic movements after death—Influence of the nervous system upon the peristaltic movements.

Action of the Bile in Digestion.

A GREAT deal of diversity of opinion has existed among physiologists concerning the functions of the bile. It is now pretty generally acknowledged that this fluid has, of itself, no marked influence upon any of the different classes of alimentary principles, such as we have observed in the other secretions which are discharged into the alimentary canal. This being the case, it is important to decide whether the bile is essential in assisting or modifying the action of other secretions, or whether it is entirely inert in the digestive process. From the fact that it is poured into the upper part of the small intestine, it would seem that it must have some office, either in modifying the digestion and absorption of food, or in the passage of alimentary substances or their residue down the intestinal tract. It is difficult to suppose that a fluid which is brought in contact with the alimentary mass in that portion of the intestine where the most important digestive processes commence should be simply excrementitious; yet

this is the view entertained by some experimentalists, more especially Blondlot. In this position of the subject, naturally the first question to decide is concerning the excrementitious or recrementitious character of the bile; or whether, in other words, it is separated from the blood simply to be discharged from the body, or has some important function to perform as a secretion.

An apparently simple method of settling this question has been employed by many experimenters, but with results which are not satisfactory unless they can be in some way harmonized. Schwann, Nasse, Bidder and Schmidt, and Bernard, whose observations will be more fully considered hereafter, have performed experiments upon animals in which the bile was entirely shut off from the intestine and discharged from the body by a fistula. If the bile be simply excrementitious, it should follow that animals operated upon in this way would not suffer from the discharge of the bile by a fistula and its diversion from the intestine; but in all of them, death occurred with symptoms pointing to defective nutrition consequent upon grave disorder of digestion. The same result followed our own experiments on this subject. On the other hand, Blondlot attempts to show that the bile is simply an excretion, and that animals thrive and will live for an indefinite period when it is diverted from its natural course and discharged from the body.

In the experiments of Blundell, Brodie, and others, who simply closed the ductus communis choledochus, the effects of shutting off the bile from the intestine were modified by the consequent undue accumulation of this fluid in the biliary passages. The only way to obviate this difficulty was to discharge the bile by a fistula, as was first done by Schwann. The first experiments reported by Schwann were made upon sixteen dogs and one rabbit. Of these, only six can be regarded as successful; and in the others, the animals either died of peritonitis resulting from the operation, or recovered, the fistulous opening into the gall-bladder becoming closed

and the communication between the liver and the intestine reëstablishing itself. These six animals died, apparently of inanition, respectively, after seven, thirteen, seventeen, twenty-five, sixty-four, and eighty days. In all, except the two animals that lived for sixty-four and eighty days, respectively, there was gradual diminution in weight from the date of the operation, notwithstanding that a large quantity of food was taken. In the two exceptions, there was first diminution in weight, then the flesh was partially regained, but it subsequently diminished until death occurred.[1] In these six animals there was every reason to believe that death occurred from the loss of the digestive function of the bile, and the disturbances in nutrition were very much like those produced by Bernard by destruction of the pancreas. These experiments were confirmed in their essential particulars by Bidder and Schmidt, Nasse, and Bernard. In an observation reported by Bernard, the animal died two months after the operation, having presented gradual emaciation accompanied by great voracity.[2]

These facts seem to show that the bile is not simply an excrementitious fluid, and that its function, after it is discharged into the intestine, is not only important, but absolutely essential to life. The only experiment which is opposed to this view is one reported by Blondlot.

The experiment by Blondlot was made upon a dog. The fistula was established in the fundus of the gall-bladder, the ductus communis having been tied and a portion exsected, after the method employed by Schwann. Fifteen days after the operation, the animal had become extremely thin, but ate well, and, according to the report of the experimenter, was in perfect health. During all this time, how-

[1] SCHWANN, *Expériences pour constater si la Bile joue dans l'Économie Animale un Rôle essentiel pour la Vie.—Mémoire lu à la Séance de l'Académie Royale du 6 juillet, 1844.—Nouveaux Mémoires de l'Académie Royale des Sciences et Belles-lettres de Bruxelles*, Bruxelles, 1846, tome xviii.

[2] BERNARD, *Liquides de l'Organisme*, Paris, 1859, tome ii., p. 199.

ever, he habitually licked the bile, but was finally prevented from doing this by a muzzle. From the moment when the dog ceased to swallow the bile, the nutrition began to improve, and in three months he had recovered the natural amount of flesh.[1] A further account of this experiment is given by Blondlot in another memoir.[2] The animal, while in perfect health, aside from the existence of the fistula, was claimed by the owner, from whom it had been stolen before it passed into the hands of the experimenter. With the fistula still open, the dog was used by its owner for hunting and lived for five years. At the end of this time it was returned to M. Blondlot, but died while in his possession, two months after.

The important question then to determine was that the bile had been completely shut off from the intestinal canal. An examination of the parts was consequently made, in the presence of a number of physicians and students. On the most minute dissection, it was impossible to find any communication between the bile-duct and the duodenum; and the conclusion arrived at was that the animal had lived for five years without a drop of bile passing into the intestine, and, consequently, that this fluid was useless in digestion.

The facts obtained by all other observers are in direct opposition to the above experiment. After a number of trials, we succeeded in establishing a biliary fistula in a dog, the operation being followed by no inflammation of the peritoneum, and notwithstanding that the animal was voracious and consumed daily large quantities of food, it died in thirty-eight days, of inanition.[3] If our own observation and those of other experimenters be correct, it is impossible that an ani-

[1] Blondlot, *Essai sur les Fonctions du Foie et de ses Annexes*, Paris, 1846, p. 55 *et seq.*

[2] Blondlot, *Inutilité de la Bile dans la Digestion proprement dite, mémoire complémentaire de l'Essai sur les Fonctions du Foie*, Paris, 1851.

[3] *Experimental Researches into a new Excretory Function of the Liver.—American Journal of the Medical Sciences*, October, 1862. The details of this experiment will be given further on, when we come to treat of the actual function of the bile in digestion.

mal should live in perfect health for years with all the bile discharged by a fistula.

There is reason to believe that the experiment of Blondlot was inaccurate, and that a communication existed between the bile-duct and the duodenum, which was not discovered at the dissection after death. The following observation strengthens us in this opinion:

We made an attempt on one occasion to ascertain the total amount of bile secreted in twenty-four hours; and with this view, the ductus communis choledochus was exposed in a dog; the bile contained in the gall-bladder was pressed out; a canula, with an elastic bag attached, was fixed in the duct; and the external wound closed, leaving the end of the canula, with the bag attached, protruding from the abdomen. The bag ruptured twenty-three hours after, and the experiment was consequently unsuccessful in the end for which it was undertaken. The tube dropped out at the end of forty-eight hours, and the external wound quickly healed. Thirty days after the operation, the animal was killed. He had then entirely recovered, and no bile had been discharged externally for a long time. The alvine dejections were perfectly normal, and there could be no doubt that the bile was regularly discharged into the duodenum. On dissection after death, the liver was found normal, and the papilla which marks the opening of the bile-duct into the duodenum was natural in appearance. It was with the greatest difficulty, however, that the communication between the bile-duct and the duodenum could be found; yet, after patient searching for more than an hour, a small tortuous tract was discovered. Had it not been certain that bile had been constantly discharged into the intestine, it might have been assumed, even after careful examination, that no such communication existed.[1] This examination convinced us that it was possible that the communication between the duct and the intestine had been

[1] *Op. cit.,—American Journal of the Medical Sciences*, October, 1862.

reëstablished in Blondlot's case, and that it had escaped observation in the dissection after death.

One point in the observations of Blondlot which makes it evident that all the bile was not discharged by the fistula is the repeated statement that the animal was perfectly well, and no one would know from its appearance that it had a fistula. In our own experiment, the lower part of the abdomen and the legs were covered with a thick coating of incrusted bile, and it was impossible to keep the parts clean. This must take place if all the bile be discharged by a fistula, and could hardly fail to attract the attention of every one.

The isolated experiment of Blondlot does not therefore invalidate the results obtained by Schwann and confirmed by so many eminent physiologists. The bile is not simply an excretion, but has an important and essential office to perform in the process of intestinal digestion. We have, however, conclusively shown that, in addition to its recrementitious function, it separates from the blood an important excrementitious principle, cholesterine, which, under a modified form, is discharged in the fæces.[1] This function of the liver will be fully considered under the head of excretion. It is sufficient for our present purposes to show that the bile, unlike any other fluid in the organism, has two distinct functions, dependent upon two distinct classes of constituents. The peculiar principles known as the biliary salts, which are produced first in the liver, give it its digestive properties; and the cholesterine, which is simply separated from the blood by the liver, gives it its excrementitious character.

As we are much better acquainted with the excrementitious than with the digestive function of the bile, we will only consider, in this connection, a few of the points concern-

[1] See an article by the author, entitled *Experimental Researches into a New Excretory Function of the Liver; consisting in the removal of Cholesterine from the Blood, and its discharge from the Body in the form of Stercorine (the Seroline of Boudet).*—*American Journal of the Medical Sciences*, October, 1862.

ing the chemistry of this fluid; deferring a full account of its composition until we come to treat of it as an excretion.

The bile varies in color and consistence in different animals. It usually has a greenish, yellowish, or brownish hue. In the human subject, it has a dark golden-brown color, and is somewhat viscid in consistence, chiefly from admixture with the mucus of the gall-bladder. The specific gravity of human bile has been found to be about 1,018.[1] Its reaction is faintly alkaline.

Physiological chemists have long since recognized in the bile peculiar principles, which are found in no other part of the organism; but the exact nature of these constituents was first described by Strecker, in 1848. The principle described by Berzelius under the name of biliary matter, subsequently separated by Thenard into two principles, called by him biliary resin and picromel, and afterward treated of by Tiedemann and Gmelin, who obtained two substances, which they called taurine and cholic acid, was analyzed by Strecker, who obtained from the bile of the ox two acids, cholic and choleic acid, which he found existed in this fluid in combination with soda.[2] The results of these researches by Strecker into the chemistry of the bile, the most extended and accurate which had ever been made, are now generally accepted by physiologists. The cholic acid of Strecker, which may be decomposed into a new acid and a principle called glycine, and the choleic acid from which may be formed a new acid and taurine, are called by Lehmann, respectively, glycocholic and taurocholic acid.[3] In the bile of the ox, these are found combined with soda, and the peculiar proximate principles of this fluid are now recognized as the glycocholate of soda, a

[1] DALTON, *Human Physiology*, Philadelphia, 1864, p. 175.

[2] STRECKER, *Untersuchung der Ochsgalle.—Annalen der Chimie und Pharmacie*, Heidelberg, 1848, Bd. lxv. S. 1 *et seq.*; and Bd. lxvii., S. 1 *et seq.*; *Beobachtungen über die Galle verschiedener Thiere*, Idem, 1849, Bd. lxx., S. 149 *et seq.* An analysis of the above is given in the *Journal de Pharmacie et de Chimie*, Paris, 1848, tome xiii., p. 215; 1849, tome xv., p. 153; and tome xvi., p. 450.

[3] LEHMANN, *Physiological Chemistry*, Philadelphia, 1855, vol. ii., p. 201 *et seq.*

crystalline substance, and the taurocholate of soda, which is of a resinous consistence, and is stated to be uncrystallizable.

The whole subject of the constitution of the bile has been admirably reviewed by Dalton, who has made, in addition, important original researches into the constitution and physiology of this fluid.[1] In the human bile, Dalton has found a resinous substance, which, from its behavior with various reagents, is undoubtedly analogous to the taurocholate of soda of ox-bile, but which he could not obtain in a crystalline form.[2]

In addition to the biliary salts, the bile contains the ordinary inorganic salts, found in nearly all the animal fluids, a small quantity of fat, the oleates, margarates, and stearates of soda and potassa, mucus from the gall-bladder, and cholesterine; the last being an excrementitious product. The action of the bile in digestion, whatever its nature may be, undoubtedly depends chiefly upon the biliary salts, and perhaps to some extent upon its saponaceous constituents.

Experiments on the action of the bile upon different alimentary substances out of the body have not led to any definite results. It is only in connection with the other digestive fluids that it seems to be efficient; and the only observations which have thrown any light upon the subject are those made upon digestion in the living organism. Simple ligation of the bile-duct, as was practised by Blundell, Brodie, Magendie, Mayo, and others, has taught us very little regarding the effects of shutting off the bile from the intestine; for the immediate effects of the operation generally interfered with the process of digestion, and subsequently the experiment was necessarily disturbed by the effects of the retention of bile in the excretory passages. As would nat-

[1] DALTON, *On the Constitution and Physiology of the Bile.—American Journal of the Medical Sciences*, October, 1857.

[2] Since writing the above, we have been informed by Professor Dalton that he has succeeded in obtaining a small quantity of crystalline matter from the human bile.

urally be expected, these observations have been quite contradictory. Brodie found no white chyle in the lacteals after the duct had been tied,[1] while Magendie, in two similar experiments, found that the chyle was formed without the aid of the bile.[2] Of others who have repeated these experiments, some have confirmed the observations of Brodie, and some, those of Magendie.

The results of experiments upon the digestive function of the bile have not been very definite; but those which have been most satisfactory have followed the establishment of a fistulous opening into the gall-bladder, the flow of bile at the same time being completely shut off from the intestine. In all experiments of this kind in which fatal inflammation did not follow the operation, death has taken place from inanition, notwithstanding an increase in the quantity of food taken. Schwann has shown that this result is not due simply to the loss of the solid matter discharged in the bile, which is small in proportion to the total daily loss of weight.[3] It undoubtedly proceeds from disordered nutrition, which has its starting point in disordered digestion.

We have now to study the modifications in digestion and nutrition which are the result of simply diverting the bile from the intestine. With that view we followed carefully these changes in the animal with a biliary fistula, that was under our own observation. This experiment confirmed, in all important particulars, those of Schwann and of Bidder and Schmidt. It is given here somewhat in detail, for inasmuch as no inflammation followed the operation and nothing occurred to complicate the effects of the diversion of the bile from the intestine, we regarded the experiment as remarkably successful.

[1] Brodie, *Expériences sur l'Usage de la Bile dans la Digestion.—Journal de Physiologie*, Paris, 1823, tome iii., p. 93.

[2] Magendie, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 118.

[3] *Loc. cit.*

Observations on a Dog with Biliary Fistula.—November 15, 1861, a biliary fistula was established in a young cur-dog weighing twelve pounds. The abdominal organs were very little exposed, and the experiment, from the first, promised to be very satisfactory. The bile-duct was first ligated next the intestine and at its junction with the cystic duct, and the intermediate portion exsected. The incision in the abdomen was in the median line just below the ensiform cartilage, and was about three inches long. The fundus of the gall-bladder was then drawn to the upper portion of the wound, and the bile was evacuated by a small opening, the edges of which were attached to the abdominal parietes. The wound in the abdomen was then closed, except the opening into the gall-bladder, into which a few shreds of lamp-wicking were introduced.

The animal appeared to do perfectly well after the operation, and ate the usual quantity the next day. He was kept in a warm room, though the weather was mild; and a careful record was made of his condition every day. The fistula occasionally showed a tendency to close, but it was kept open by the occasional introduction of a glass rod. From time to time, while the animal was under observation, he licked the bile as it flowed from the fistula. This was finally prevented by a long wire-muzzle, the sides of which were covered with oil-silk.

The abdomen was somewhat tumid, with some rumbling in the bowels, for five days after the operation. The first alvine discharge took place on the evening of the second day. The fæces seemed in all regards normal. After that time, they became very infrequent, though the animal ate well every day. The fæces that were passed after the third day were of a grayish color and moderately soft. They had an exceedingly offensive and penetrating odor. At about the fifteenth day, the fæces became more frequent; and from that time were passed three or four times a day. Generally they were clay-colored; but on one or two occasions

were quite dark. They always had a peculiarly offensive odor.

The weight of the animal remained stationary for about four days. On the sixth day (November 20th) the weight began to diminish. He weighed on that day, before feeding, eleven and one quarter pounds. November 22d, he weighed but little over eleven pounds. November 24th, he weighed ten pounds. He maintained this weight until December 1st, when the weight again began to diminish. On December 6th, the weight was nine pounds. On December 7th, the weight was reduced to eight and a half pounds, and the strength began to fail manifestly. December 10th and 11th, he gained a little, on those days weighing nine pounds; but after that, he progressively diminished in strength and in weight until death occurred, thirty-eight days after the operation. The weight was then seven and a half pounds, showing a total loss of four and a half pounds, or $37\frac{1}{2}$ per cent.

During the first nine days of the observation the animal ate well, but not ravenously, taking about three-quarters of a pound of beef-heart daily. On the tenth day the appetite increased. He ate on that day, at one time a pound, and at another, half a pound of meat. He ate on an average about a pound and a half of beef-heart daily, until the day before his death. During the last five or six days he seemed very ravenous, and was not allowed to eat all that he would at one time. At this time he was ordinarily fed twice a day. He would not eat fat, even when very hungry. During the last day, when too weak to stand, he attempted to eat while lying down. During the last twelve days of the observation, he attempted constantly to eat the fæces.

During the last days of the experiment, when the dog had become much reduced in weight, he became very cross, and snapped at every animal that came near him. There was never any icterus, fetor of the breath, or falling off of the hair.

A careful examination of the animal was made after

death. The gall-bladder was somewhat contracted but not obliterated, and the fistula would admit the largest-sized male catheter. Both ends of the divided bile-duct were found impervious. There was no passage for the bile into the intestine. The abdominal organs were normal, with the exception of evidences of slight peritoneal inflammation around the wound and over the convex surface of the liver. There was no fat in the omentum or anywhere in the body, except a very small quantity at the bottom of the orbit.

The above observation is a type of the instances—which are not very numerous—in which the bile has been completely shut off from the intestine and discharged externally by a fistula into the gall-bladder. As far as could be ascertained, this animal, from the first, presented no disturbances which were not due solely to the absence of the bile from the intestine, and its discharge externally. Though the phenomena here presented do not teach us much that is definite concerning the digestive action of the bile, taken in connection with what has been ascertained concerning the general properties of this secretion, they throw some light upon its function.

One of the functions which has been ascribed to the bile is that of regulating the peristaltic movements of the small intestine, and of preventing putrefactive changes in the intestinal contents and the abnormal development of gas. Experiments on this point are somewhat conflicting. Our own observations would lead us to doubt the constant influence of the bile upon the peristaltic movements. During the first few days of the experiment, the dejections were very rare; but they afterward became regular, and at one time, even, there was a tendency to diarrhœa. There can be no doubt, however, that the bile retards the putrefaction of the contents of the intestinal canal, particularly when animal food has been taken. The fæces in the dog, as far as our own observation goes, were always extremely offensive. Bidder and Schmidt found this to be the case in dogs fed entirely on meat; but the fæces were nearly odorless when the ani-

mals were fed on bread alone.[1] In the case of intestinal fistula in the human subject, the evacuations which took place after the introduction of alimentary substances into the lower portion of the intestine had an unnaturally offensive and putrid odor. In this case, as it was impossible for matters to pass from the portions of the intestine above the fistula to those below, the food introduced into the lower opening was completely removed from the action of the bile.

So far as the digestion of the different alimentary principles is concerned, it has been shown that the bile, of itself, has no particular action upon any of them. In the fæces of animals with biliary fistula, the only peculiarity which has been observed, aside from the putrefactive odor and the absence of the coloring matter of the bile, has been the presence of an abnormal proportion of fat. We have observed this in the fæces of a patient suffering under jaundice apparently due to temporary obstruction of the bile-duct.[2] This fact was noted in the dogs experimented upon by Bidder and Schmidt.

The various experiments which have been performed upon animals render it almost certain that the bile has an important influence, either upon the digestion or the absorption of fats. The observations of Brodie and others, in which the bile-duct was simply ligated, are not very conclusive, as the disturbances produced by the retention of the bile probably had an influence upon digestion and absorption; but Bidder and Schmidt noted in animals with biliary fistula that the chyle contained very much less fat than in health. In an animal with a fistula, and the bile-duct obliterated, the proportion of fat was 1·90 parts to 1,000 parts of chyle; while

[1] *Op. cit.*, p. 218.

[2] *American Journal of the Medical Sciences*, October, 1862. We obtained from 941·4 grains of fæces taken from this patient, a cake of soap weighing thirty-four grains. In an analysis of the fæces made nineteen days after, when the patient had recovered, no saponifiable fat was found.

in an animal with the biliary passages intact, the proportion was 32·79 parts per 1,000.[1]

In animals operated upon in this way, there is frequently a great distaste for fatty articles of food. In our own observation, the dog refused fat meat even when very hungry and when lean meat was taken with great avidity.

Experiments concerning the influence of the bile upon the absorption of fats have resulted in hardly any thing definite. We only know the fact that when the bile is diverted from the intestine, the proportion of fat in the chyle is greatly reduced, and a large proportion of the fat taken with the food passes through the intestine and is found in the fæces.

The action of the bile in exciting muscular contraction, particularly in the smooth muscular fibres, is pretty well established. It has been shown by Schiff that this fluid acts upon the muscular fibres situated in the substance of the intestinal villi, causing them to contract, and, according to his view, assisting in the absorption of chyle by emptying the lacteals of the villi.[2] The whole subject, however, of the absorption of fats is exceedingly difficult of investigation; and our knowledge of it has not been sensibly advanced by the experiments upon the influence exerted by the bile.

Notwithstanding the obscurity in which this subject is involved, it is certain that the progressive emaciation, loss of strength, and final death of animals deprived of the action of the bile in the intestine is due to defective digestion and assimilation. In spite of the great quantities of food taken by these animals, the phenomena which precede the fatal result are simply those of starvation. It may be that the biliary salts are absorbed by the blood and are necessary to proper assimilation; but there is no experimental basis for this supposition, and it is impossible to discover these salts in the blood of the portal system by the ordinary tests. It is more probable that the biliary salts influ-

[1] *Op. cit.*, p. 227.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 256.

ence in some way the digestive process and are modified and absorbed with the food.

The observations of Bidder and Schmidt show conclusively that the characteristic constituents of the bile are absorbed in their passage down the alimentary canal. Having arrived at a pretty close estimate of the quantity of bile daily produced in dogs, they collected and analyzed all the fæcal matter passed by a dog in five days. Of the dry residue of the fæces, the proportion which could by any possibility represent the biliary matters did not amount to one-fourth of the dry residue of the bile which must have been secreted in that time. They also estimated the total quantity of sulphur contained in the fæces, and found that the entire quantity was hardly one-eighth of that which was discharged into the intestine in the bile; and inasmuch as nearly one-half of that found in the fæces came from hairs which had been swallowed by the animal, the experiment showed that nearly all the sulphur contained in the non-crystallizable element of the bile (the taurocholate of soda) had been taken up again by the blood.[1] These observations show conclusively that the greater part of the bile, with the biliary salts, is absorbed by the intestinal mucous membrane. Prof. Dalton has attempted to follow these principles into the blood of the portal system, but has never been able to detect the biliary salts, by the most careful analysis.[2] Like the peculiar principles of other secretions which are reabsorbed in the alimentary canal, these substances become changed and are not to be recognized by the ordinary tests, after they are taken into the blood.

Although it is the digestion and absorption of fatty substances which seem to be most seriously interfered with in cases of biliary fistula in the inferior animals, the rapid loss of weight and strength would indicate great disturbance in

[1] Bidder und Schmidt, *Die Verdauungssäfte*, Leipzig, 1852, S. 217, 218.

[2] Dalton, *Treatise on Human Physiology*, Philadelphia, 1864, pp. 179 and 198.

the digestion and absorption of other articles of food. A fact which indicates a connection between the bile and the process of digestion is that the flow of this secretion, though constant, is greatly increased when food passes into the intestinal canal. This has been noted by all who have experimented on the subject. The following observations on a dog, showing the variations in the flow of bile from the fistula, were made twelve days after the fistula had been established, when the weight of the animal had been reduced from twelve to ten pounds:

Table of Variations in the Flow of Bile with Digestion.[1]

(At each observation, the bile was drawn for precisely thirty minutes.)

TIME AFTER FEEDING.	Fresh Bile.	Dried Bile.	Percentage of Dry Residue.
	Grains.	Grains.	
Immediately	8·103	0·370	4·566
One hour	20·527	0·586	2·854
Two hours	35·760	1·080	3·023
Four hours	38·939	1·404	3·605
Six hours	22·209	0·987	4·450
Eight hours	36·577	1·327	3·628
Ten hours	24·447	0·833	3·407
Twelve hours	5·710	0·247	4·325
Fourteen hours	5·000	0·170	3·400
Sixteen hours	8·643	0·309	3·575
Eighteen hours	9·970	0·277	2·778
Twenty hours	4·769	0·170	3·565
Twenty-two hours	7·578	0·293	3·866

Disregarding slight variations in this table, which might be accidental, it may be stated, in general terms, that the bile commences to increase in quantity immediately after eating; that its flow is at its maximum from the second to the eighth hour, during which time the quantity does not vary to any great extent; after the eighth hour it begins to

[1] The entire quantity of bile in the twenty-four hours, estimated from these observations by taking an average of the quantities obtained in all the observations and multiplying by forty-eight, was 833·933 grains, with 30·003 grains of dry residue. The question of the entire quantity of bile produced by the human subject in the twenty-four hours will be considered hereafter under the head of excretion.

diminish, and from the twelfth hour to the time of feeding, it is at its minimum.[1] The experiments of Dr. Dalton, made on a dog with a fistula into the duodenum, show "that the bile passes into the intestine in by far the largest quantity immediately after feeding, and within the first hour."[2]

Though it has been pretty satisfactorily demonstrated that the presence of the bile in the small intestine is necessary to proper digestion, and even essential to life, and though the variations in the flow of bile with digestion are now well established, it must be confessed that we have hardly any definite information concerning the mode of action of the bile in intestinal digestion and absorption. In all probability, its action is auxiliary to that of the other digestive fluids.

Movements of the Small Intestine.

By the contractions of the muscular coats of the small intestine, the alimentary mass is made to pass along the canal, sometimes in one direction, and sometimes in another; the general tendency, however, being toward the cæcum. The partially digested matters which pass out at the pylorus are prevented from returning to the stomach, by the peculiar arrangement of the fibres which constitute the pyloric muscle. The passage from the stomach to the intestine, as we have seen, becomes constricted gradually, so that food of the proper consistence finds its way easily into the duodenum;

[1] There is some difference in the observations of different experimenters concerning the variations in the flow of bile with digestion. Bidder and Schmidt (*op. cit.*) found that the flow began to increase about two hours after feeding, its maximum being at from twelve to fifteen hours after; Arnold (*American Journal of the Medical Sciences*, April, 1856, p. 467) found the maximum to occur soon after feeding, decreasing after the fourth hour; and Kölliker and Müller (*American Journal of the Medical Sciences*, April, 1857, p. 476) found the maximum to be between the sixth and the eighth hour.

[2] DALTON, *Constitution and Physiology of the Bile.—American Journal of the Medical Sciences*, October, 1857, p. 317, and *Treatise on Human Physiology*, Philadelphia, 1864, p. 190.

but viewed from the duodenal side, the constriction is abrupt, so that regurgitation is generally difficult.[1]

Once in the intestine, the food is propelled along the canal by peculiar movements, which have been called peristaltic, when their direction is toward the large intestine, and antiperistaltic, when the direction is reversed. These movements are of the character peculiar to the unstriped muscular fibres; *i. e.*, slow, gradual, the contraction enduring for a certain time, and followed by a correspondingly slow and gradual relaxation. Both the circular and the longitudinal muscular layers participate in these movements. If we carefully watch this action in the intestines of an animal after the abdomen has been opened, we can sometimes see a gradual constriction produced by the action of the circular fibres at a certain point, which is slowly propagated along the tube, while, at the same time, the longitudinal fibres are alternately contracted and relaxed in the same gradual manner, shortening and elongating the tube and facilitating the onward passage of its contents. It can readily be appreciated how movements of this kind are capable of propelling the alimentary mass slowly but certainly along the intestinal tract, even when the direction is in opposition to the force of gravity; and how admirably these movements are calculated

[1] When the stomach is empty, the pylorus is relaxed, so that the bile frequently passes in from the duodenum; but as soon as the food is passed into the stomach by the œsophagus, the pylorus becomes firmly closed. It is stated by Magendie (*Précis Élémentaire de Physiologie*, Paris, 1836, p. 83), and this view is adopted by some physiologists, that the pylorus allows matters to pass with difficulty from the stomach to the intestine, but that regurgitation from the intestine to the stomach is comparatively easy. This opinion is based upon an experiment of Magendie, in which he showed that air contained in the stomach could not be forced into the intestine by pressure with the hands, while the pressure easily passed air from the duodenum into the stomach. (*Loc. cit.*) It must be remembered, however, that the muscular fibres of the pylorus are connected with the stomach, and not with the intestine; and that pressure exerted upon the stomach would cause them to contract, but pressure upon the duodenum would have no such effect. We have already noted that during a quiescent condition of the stomach, these fibres are relaxed.

to thoroughly incorporate the food with the digestive fluids and expose those parts which have been completely liquefied to the absorbent action of the mucous membrane.

Though the mechanism of the propulsive movements of the intestine may be studied in living animals after opening the abdomen, or, better still, in animals just killed, the movements thus observed do not entirely correspond with those which take place under natural conditions. In vivisections, no movements are observed at first; but soon after exposure of the parts, nearly the whole intestine moves like a mass of worms. In the normal process of digestion, the movements are never so general nor so active; they take place more regularly and consecutively in those portions in which the contents are most abundant, and the movements are intermittent, being interrupted by long intervals of repose. In Prof. Busch's case of intestinal fistula, there existed a large ventral hernia, the coverings of which were so thin that the peristaltic movements could be readily observed. In this case, the general character of the movements corresponded with what has been observed in the inferior animals. It was noted that the movements were not continuous, and that there were often intervals of rest for more than a quarter of an hour. It was also observed that the movements, as indicated by flow of chymous matter from the upper end of the intestine, were intermitted with considerable regularity during part of the night. After ten or eleven P. M., no discharge took place for six or seven hours. Antiperistaltic movements, producing discharge of matters which had been introduced into the lower end of the intestine, were frequently observed.

As far as has been ascertained by observations upon the human subject and warm-blooded animals, the regular intestinal movements are excited by the passage of alimentary matter from the stomach through the tube during the natural process of digestion. By a very slow and gradual action

[1] *Loc. cit.*

of the muscular coat of the intestine, its contents are passed along, occasionally the action being reversed for a time, until the indigestible residue, mixed with a certain quantity of intestinal secretion, more or less modified, is discharged gradually into the caput coli. These movements are apparently not continuous, and depend somewhat upon the quantity of matter contained in different parts of the intestinal tract. If we are to judge from the movements in the inferior animals after the abdomen has been opened, the intestines are constantly changing their position, principally by the action of their longitudinal muscular fibres, so that the force of gravity does not oppose the onward passage of their contents as much as if the relative position of the parts were constant. There are no definite observations concerning the relative activity of the peristaltic movements in different portions of the intestine; but from the fact that the jejunum is constantly found empty, while the ileum contains a considerable quantity of pultaceous matter, it would seem that the movements must be more vigorous and effective in the upper portions of the canal.

The gases which are constantly found in the intestine have, according to Longet,[1] an important mechanical function. They are useful, in the first place, in keeping the canal constantly distended to the proper extent, thus avoiding the liability to disturbances in the circulation, and facilitating the passage of the alimentary mass in obedience to the peristaltic contractions. They also support the walls of the intestine and protect these parts against concussions in walking, leaping, etc. The gases are useful, likewise, in offering an elastic but resisting mass upon which the compressing action of the abdominal muscles may be exerted in the acts of straining and expiration. If we could suppose the intestinal tube to be entirely free from gaseous contents, it is evident that the functions above mentioned would be performed imperfectly and with difficulty.

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 152.

There can be hardly any question that the normal movements of the intestine are principally due to the impression made upon the mucous membrane by the alimentary matters, to which is added, perhaps, the stimulant action of the bile. It is difficult to determine with accuracy what part the bile plays in the production of these movements, from the fact that the normal action of the intestine is not easily observed. In the case of intestinal fistula so often referred to, when food was introduced into the lower end of the canal, there was at first an abundant evacuation every twenty-four hours; but subsequently it became necessary to use enemeta. As there was no communication between the lower and the upper end of the intestine, this fact is evidence that the peristaltic movements can take place without the action of the bile. Experiments upon the inferior animals concerning the influence of the bile upon the peristaltic movements are somewhat contradictory. When the abdomen is opened during life, vigorous movements may sometimes be excited by pressing bile into the intestine from the gall-bladder; and the same result is occasionally observed when the bile is applied to the peritoneal surface in an animal recently killed. But the various experiments in which the bile has been diverted from the intestine and discharged by a fistula, taking the frequency of the alvine dejections as a test, show that regular peristaltic movements may take place without the intervention of the bile.

The vigorous peristaltic movements which occur soon after death have been explained in various ways. It has been shown that these movements are not due to a lowering of the in temperature, or to exposure of the intestines to the air. The latter fact may be easily verified by killing a rabbit, when vigorous movements may be seen through the thin abdominal walls, even while the cavity is unopened. According to Schiff, the only cause of these exaggerated movements is diminution or arrest of the circulation. This physiologist, by compressing the abdominal aorta in a living animal, was able

to excite peristaltic movements in the intestine as vigorous as those which take place after death; and on ceasing the compression, the movements were arrested.[1]

The nerves which are distributed to the small intestine are derived almost exclusively from the sympathetic system. The only part receiving filaments from the cerebro-spinal centres is the commencement of the duodenum, to which are distributed a few branches from the pneumogastric. The experiments of Brachet,[2] by which he attempted to prove that the movements of the intestines were under the control of the pneumogastric and nerves emanating from the spinal cord, have not been verified by other observers. Recent experiments render it probable that an influence, derived from the cerebro-spinal system, is essential to the functions of the sympathetic ganglia,[3] which may account for some of the results obtained by Brachet after dividing the spinal cord. The experiments of Müller, however, render it certain that the peristaltic movements are to some extent under the influence of the sympathetic nerves distributed to the intestines. In these experiments, movements of the intestine were produced by galvanization of filaments of the sympathetic distributed to its muscular coat, after the ordinary post-mortem movements had ceased. The same results followed the application of caustic potash to the semilunar ganglia, the movenents reappearing when the potash was applied, "with extraordinary vivacity" in the rabbit after the abdomen had been opened and the movements had entirely ceased.[4] These experiments have been confirmed by Longet, who found, however, that the movements did not take place

[1] SCHIFF, in LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 147.

[2] BRACHET ET FOUILHOUX, *Encyclopédie des Sciences Médicales* (*Anatomie et Physiologie*), Paris, 1840, tome v., p. 258.

[3] BERNARD, *Recherches Expérimentales sur les Nerfs Vasculaires et Calorifiques du grand Sympathique.—Journal de la Physiologie*, Paris, 1862, tome v., p. 383.

[4] MÜLLER, *Physiologie du Système Nerveux*, Trad. par Jourdan, Paris, 1840, tome i., p. 122.

unless alimentary matters were contained in the intestine.[1]

It must be acknowledged that very little is known concerning the reflex actions which take place through the sympathetic system; but there is certainly good ground for supposing that certain reflex functions are performed by this system of nerves, one of the most important of which is the production of peristaltic movements in obedience to the impression made by alimentary substances upon the mucous membrane. This impression is probably conveyed to the semilunar ganglia and reflected back through the motor nerves to the muscular coat of the intestine.

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 148.

CHAPTER XIV.

ACTION OF THE LARGE INTESTINE.

Physiological anatomy of the large intestine—Divisions of the large intestine—Ileo-cæcal valve—Digestion in the large intestine—Contents of the large intestine—Composition of the fæces—Microscopic characters of the fæces—Excretine and excretoleic acid—Stercorine—Origin of stercorine—Summary of the constitution of the fæces—Movements of the large intestine—Defecation—Action of the sphincter and the levator ani—Gases found in the alimentary canal—Origin of the intestinal gases.

Physiological Anatomy of the Large Intestine.

THE large intestine, so called because its diameter is greater than that of the rest of the intestinal tract, receives for the most part only the indigestible residue of the food, mingled with certain of the secretions which are discharged into the small intestine. In the human subject, the processes of digestion which take place in this part of the alimentary canal are unimportant; and it is probable that hardly any thing but water is absorbed by its lining membrane. Matters are, however, stored up in the large intestine for a number of hours, and a certain amount of secretion takes place from its follicular glands.

The entire length of the large intestine is from four to six feet. Its diameter is greatest at its commencement, where it measures, when moderately distended, from two and a half to three and a half inches. According to the observations of Brinton, the average diameter of the tube beyond the cæcum is from one and two-thirds to two and two-thirds

inches.[1] Passing from the cæcum, the canal diminishes in calibre, gradually and very slightly, to where the sigmoid flexure opens into the rectum. This is the narrowest portion of the canal. Beyond this, the rectum gradually increases in diameter, forming a kind of pouch, which abruptly diminishes in size near the external opening, to form the anus.

The general direction of the large intestine is from the cæcum in the right iliac fossa, to the left iliac fossa, thus surrounding the convoluted mass formed by the small intestine, in the form of a horse-shoe. From the cæcum to the rectum the canal is known as the colon. The first division of the colon, called the ascending colon, passes almost directly upward to the under surface of the liver; the canal here turns at nearly a right angle, passes across the upper part of the abdomen, and is called the transverse colon; it then passes downward at nearly a right angle, forming the descending colon. The last division of the colon, called the sigmoid flexure, is situated in the left iliac fossa and is in the form of the italic letter *S*. This terminates in the rectum, which is not straight, as its name would imply, but presents at least three distinct curvatures, as follows: it passes first in an oblique direction from the left sacro-iliac symphysis to the median line opposite the third piece of the sacrum; it then passes downward, in the median line, following the concavity of the sacrum and coccyx; and the lower portion, about an inch in length, turns backward to terminate in the anus.

The form of the large intestine is peculiar. The cæcum, or caput coli, presents a rounded dilated cavity, continuous with the colon above, and communicating by a transverse slit with the ileum. At its lower portion is a small cylindrical tube, from one to five inches in length, opening below and a little posterior to the opening of the ileum, called the vermiform appendix. This is covered with peritoneum, and is possessed of a muscular and a mucous coat. It is sometimes en-

[1] Brinton, *Cyclopædia of Anatomy and Physiology*, London, 1859, vol. v., supplement, p. 362.

tirely free, and is sometimes provided with a short fold of mesentery for a part of its length. The coats of the appendix are very thick. The muscular coat consists of longitudinal fibres only. The mucous membrane is provided with tubules and closed follicles, the latter frequently being very numerous. This little tube, which is only about one-third of an inch in diameter, generally contains a quantity of clear, viscid mucus. Particles of fæcal matter and extraneous substances, such as seeds, sometimes find their way into its cavity, and producing ulceration, they may escape into the peritoneal cavity and induce fatal inflammation.[1] The uses of the vermiform appendix are unknown.

Ileo-cæcal Valve.—The most interesting anatomical peculiarity of the cæcum is the opening by which it receives the contents of the small intestine. This opening is arranged in the form of a valve, known as the ileo-cæcal valve, situated at the inner and posterior portion of the cæcum. The small intestine, at its termination, presents a shallow concavity, which is provided with a horizontal button-hole slit opening into the cæcum. The surface of the valve which looks toward the small intestine is covered with a mucous membrane provided with villi and in all respects resembling the general mucous lining of the small intestine. Viewed from the cæcum, a convexity is observed corresponding to the concavity upon the other side. The cæcal surface of the valve is covered with a mucous membrane identical with the general mucous lining of the large intestine. It is evident from an examination of these parts that pressure from the ileum will open the slit and allow the easy passage of the semi-fluid contents of the intestine; but pressure from

[1] During intra-uterine life, the cæcum is relatively much larger than in the adult. It afterward retracts in its lower half or two-thirds to about the diameter of a crow-quill, and this forms the appendix vermiformis. This appendix exists only in man and the quadrumana. (SAPPEY, *Traité d'Anatomie Descriptive*, Paris, 1857, tome iii., p. 202.)

the cæcal side will approximate the lips of the valve, and the greater the pressure the more firmly will the opening be closed. The valve itself is composed of folds involving the white fibrous tissue of the intestine (the cellular tunic of some anatomists), and the circular muscular fibres from both the small and the large intestine; the whole being covered with mucous membrane. The lips of the valve unite at either extremity of the slit and are prolonged on the inner surface of the cæcum, forming two raised bands or bridles; and these become gradually effaced and are thus continuous with the general lining of the canal. The posterior bridle is a little longer and more prominent than the anterior. These assist somewhat in enabling the valve to resist pressure from the cæcal side. The longitudinal layer of muscular fibres and the peritoneum pass directly over the attached edge of the valve and are not involved in its folds. These give strength to the part, and if they be divided over the valve, gentle traction will suffice to draw out and obliterate the folds, leaving a simple and unprotected communication between the large and the small intestine.

Peritoneal Coat.—Like most of the other abdominal viscera, the large intestine is covered by peritoneum. The cæcum is covered by this membrane only anteriorly and laterally. It is usually bound down closely to the subjacent parts, and its posterior surface is without a serous investment; though sometimes it is completely covered, and there may be even a short mesocæcum. The ascending colon is likewise covered only in front, and is closely attached to the subjacent parts. The same arrangement is found in the descending colon. The transverse colon is almost completely invested with peritoneum; and the two folds forming the transverse mesocolon split to pass over the tube above and below, uniting again in front to form the great omentum. The transverse colon is consequently quite movable. In the course of the colon and the upper part of the rectum, particularly on

the transverse colon, are found a number of little sacculated pouches filled with fat, called the appendices epiploïcæ. The sigmoid flexure of the colon is invested with peritoneum, except at the attachment of the iliac mesocolon. This division of the intestine is capable of considerable motion. The upper part of the rectum is almost completely covered by peritoneum, and is but loosely held in place. The middle portion is closely bound down, and is only covered with peritoneum anteriorly and laterally. The lowest portion of the rectum has no peritoneal covering.

Muscular Coat.—The muscular fibres of the large intestine have an arrangement quite different from that which exists in the small intestine. The external, longitudinal layer, instead of extending over the whole tube, is arranged in three distinct bands, which commence in the cæcum at the vermiform appendix. Passing along the ascending colon, one of the bands is situated anteriorly, and the others latero-posteriorly. On the transverse colon, the anterior band becomes inferior, and the two latero-posterior bands become respectively postero-superior and postero-inferior. On the descending colon and the sigmoid flexure, the muscular bands resume the relative position which they had on the ascending colon. As these longitudinal fibres pass to the rectum, the anterior and the external bands unite to pass down on the anterior surface of the canal, while the posterior band passes down on its posterior surface. Thus the three bands are here formed into two. These two bands as they pass downward, though remaining distinct, become much wider; and longitudinal muscular fibres commencing at the rectum are situated between them, so that this part of the canal, especially in its lower portion, is covered with longitudinal fibres in a pretty uniform layer.

The termination of the muscular fibres of the rectum has been closely studied by Sappey. He has found that as far as their terminations are concerned, the fibres may be divided

into an external, a middle, and an internal layer. The posterior fibres of the external layer pass away from the lower portion of the rectum, are reflected backward along the concavity of the sacrum, and are attached to the promontory. These fibres, which are generally pale, Sappey proposes to designate as retractors of the anus. A few of the posterior fibres are attached to the aponeurosis and the parts between the coccyx and the promontory. In front, the external fibres are attached to the aponeurosis which covers the vesiculæ seminales, and laterally they are inserted into the deep pelvic fascia. The termination of the middle layer of the fibres is less clearly made out. Those situated at the sides of the rectum are inserted into "a very dense cellulo-fibrous band, which, by its opposite surface, gives insertion to a great number of fibres of the levator ani." The others are many of them continuous with the fibres of the levator ani as they pass along the floor of the pelvis. Some of the fibres of the deep layer are attached by little tendons which pass between the external and the internal sphincter to the deep portions of the skin which encircle the anus.[1] The importance of closely studying the attachments of these fibres will be appreciated when we come to treat of defecation.

Over the cæcum and the colon, the anterior band of muscular fibres is from one-third to one-half an inch in width. The postero-external band is not more than half as wide, and the postero-internal band is even narrower. The muscular bands are much shorter than the canal itself, and their attachment to the walls gives the intestine a peculiar sacculated appearance. That this is produced by the arrangement of the muscular fibres may be demonstrated by dividing them in various places or removing them entirely, when the canal may be extended to double its original length. Between the bands there are no longitudinal muscular fibres; but circular or transverse muscular fibres exist throughout the whole length of the large intestine. In the cæcum and colon, the circular

[1] SAPPEY, *op. cit.*, pp. 226, 227.

fibres are so pale and the layers are so thin that their presence is demonstrated with great difficulty. In the rectum they are somewhat more numerous. About an inch above the anus the circular fibres are collected into a pretty well-marked muscular ring, which has been called the internal sphincter.

Mucous Coat.—The mucous lining of the large intestine presents several important points of difference from that which is found in the small intestine. It is paler, somewhat thicker, firmer, and more closely adherent to the subjacent parts. In no part of this membrane are there any folds, like those which form the valvulæ conniventes of the small intestine; and the surface is perfectly smooth and free from villosities.

Throughout the entire membrane, from the ileo-cæcal valve to the anus, are innumerable orifices which lead to simple follicular glands. These structures resemble in all respects the follicles of the small intestine, except that they are a little longer, owing to the greater thickness of the membrane, and are wider, and rather more numerous. Among these small follicular openings are found, scattered irregularly throughout the membrane, larger openings which lead to utricular glands, resembling the closed follicles, in general structure, except that they have an orifice opening into the cavity of the intestine, which is sometimes so large as to be visible to the naked eye.[1] The number of these glands is very variable, and they are irregularly disseminated throughout the intestine in company with the closed follicles, except in the rectum, where they are absent. In the cæcum and colon, a number of isolated closed follicles are generally found, which are identical in structure with the solitary glands of the small intestine. These are exceedingly variable, both in number and size.

The mucous membrane of the rectum, in the upper three-fourths of its extent, does not differ materially from that

[1] SAPPEY, *op. cit.*, tome iii., p. 192.

of the colon. In the lower fourth, the fibrous tissue by which the lining membrane is united to the subjacent muscular coat is loose, and the membrane, when the canal is empty, is thrown into a great number of irregular folds. At the site of the internal sphincter, five or six little semilunar valves have been observed with their concavities directed toward the colon. These form an irregular festooned line which surrounds the canal; their folds, however, are small and have no tendency to obstruct the passage of fæcal matters. The simple follicles are particularly abundant in the rectum, and the membrane is constantly covered with a thin coating of mucus. Another peculiarity to be noted in the mucous membrane of the lower portions of the rectum, is its great vascularity; the veins, especially, being very numerous.

Finally, the rectum terminates in the anus, a button-hole orifice, situated a little in front of the coccyx, which is kept closed and somewhat retracted, except during the passage of the fæces, by the powerful external sphincter. This muscle is composed entirely of red or striated fibres, which are arranged in the form of an ellipse, its long diameter being antero-posterior.

It is now almost universally admitted that the digestion of all classes of alimentary substances is completed either in the stomach or the small intestine, and that the mucous membrane of the large intestine does not secrete a fluid endowed with any well marked digestive properties. The simple follicles, the closed follicles, and the utricular glands, produce a glairy mucus, which, as far as we know, serves merely to lubricate the canal. This has never been obtained in sufficient quantity to admit of any accurate investigation into its properties.[1]

[1] It is now pretty generally conceded by practical physicians that it is possible to support the vital powers for a time by nutrient matters introduced into the large intestine by injection. As can readily be understood, there are obstacles in the employment of this method of alimentation which render its application difficult, if not impossible, in many cases; but instances have been reported in which it nas been used for a long time with complete success. One

In studying the changes which the alimentary mass undergoes in its passage through the small intestine, we have seen that in this portion of the canal the great part of all the nutritive material is not only liquefied, but absorbed. Sometimes fragments of muscular fibre, oil-globules, and other matters in a state of partial disintegration are to be detected in the fæces by the microscope; but generally this is either the result of taking an excessive quantity of these substances, or it depends upon some derangement of the digestive apparatus; though muscular fibres deeply colored with bile, but still distinctly striated, were constantly found in the fæces by Wehsarg.[1] When intestinal digestion takes place with regularity, the transformation of the alimentary mass into fæcal matter is slow and gradual. As the contents of the stomach are passed little by little into the duodenum, the chymous mass becomes of a bright-yellow color, and its fluidity is increased, from the admixture of bile and pancre-

of the most remarkable of these was reported in the *American Journal of the Medical Sciences*, October, 1852, by Dr. J. L. Pierce. In this case, the patient, a female about twenty-six years of age, suffered from a disorder of the stomach, in which all articles of food were rejected within a few moments after they had been taken. She was actually in danger of death from inanition, when it was proposed to nourish her entirely by enemata. Under the direction of her physician, she took injections of lamb or mutton broth, about half a pint at a time, every three hours, for about three months. During the first week of this treatment, she was allowed occasionally a little gum-arabic water or pure water, not to exceed a teaspoonful at a time; but after that, nothing was taken by the mouth. Under this treatment the patient improved in health and strength, began gradually to take food by the mouth at the end of three months, and finally recovered. (*Loc. cit.*, p. 571 *et seq.*)

It is difficult to determine whether nutritive matters thus introduced into the large intestine undergo any change which may be likened to digestion; but there can be no doubt that they are in great part absorbed. A French experimenter, M. Bouisson, reports an observation in which a dog was first purged, then kept fasting for two days, when a quantity of milk was injected into the large intestine. The animal was killed a short time after, and the lymphatics from the large intestine were found filled with white chyle. (*Études sur le Chyle.—Gazette Médicale de Paris*, 1844, tome xii., p. 522.)

[1] Wehsarg, *Mikroscopische und chemiche Untersuchungen der Faeces gesunder, erwachsener Menschen*, Giessen, 1853, p. 65.

atic fluid. In passing along the canal, the consistence of the mass gradually diminishes, from the absorption of its liquid portions, and the color becomes darker; and by the time that the contents of the ileum are ready to pass into the cæcum, the greatest part of those substances which we have recognized as alimentary principles have become changed and absorbed. The various forms of starchy and saccharine principles, unless they have been taken in excessive quantity, soon disappear from the intestine; and the glucose, which is the result of their digestion, may be recognized in the blood of the portal system. As a rule, fatty matters are not found in the lower part of the ileum, having passed into the lacteals in the form of an emulsion. Neither fibrin, albumen, nor caseine can be detected in the ileum; and, as we have seen, the muscular substance, as recognized by its microscopic characters, becomes gradually disintegrated and is lost—except a few isolated fragments deeply colored with bile—some time before the undigested residue passes into the large intestine.

In the human subject, those portions of the food which resist the successive and combined action of the different digestive secretions, are derived chiefly from the vegetable kingdom. Hard vegetable seeds, the cortex of the cereals, spiral vessels, and, in fine, all parts which are composed largely of cellulose, pass through the intestinal canal without much change. These substances form, in the fæces, the greatest part of what can be recognized as the residue of matters taken as food. It is well known that an exclusively animal diet, particularly if the nutritious principles be taken in a concentrated and readily assimilable form, leaves very little undigested matter to pass into the large intestine, and gives to the fæces a character quite different from that which is observed in herbivorous animals, or in man, when subjected to an exclusively vegetable diet. The characters of the residue of the digestion of albuminoid substances are not very distinct. As a rule, none of the albuminoids are to be recognized in the healthy

fæces by the ordinary tests. This has been ascertained by Braconnot, by experiments on pigeons, and by Blondlot, by experiments on dogs. Blondlot fed a dog for eight days with hashed beef mixed with about a quarter of its weight of liquid albumen, and never could detect either albumen or fibrin in the fæces. He fed the same dog for four days on the spongy structure of bones roughly comminuted in a mortar, and by heating the fæces with water in a Papin's digester, he was unable to extract any gelatine.[1] Of the various animal substances which may find their way into the alimentary canal, mucus is apparently the most refractory to the action of the digestive fluids, none of which seem to affect it in the slightest degree. In normal alimentation, then, the quantity of nitrogenized matter which escapes digestion is very slight, consisting chiefly of tendinous or ligamentous structure, elastic tissue, skin, and tissues of like nature. When the quantity of animal matter taken is excessive, the residue is greater, but the principles are in a putrescent condition and cannot usually be recognized by their ordinary characters.

Many insoluble inorganic substances are taken with the food and appear unchanged in the fæces. The fæces of dogs fed exclusively on bones, which were formerly administered internally as a remedy for epilepsy, under the name of *album Græcum*, are composed almost entirely of calcareous matter. With regard to the ordinary inorganic constituents of the fæces, however, it is difficult to say how much is derived from the ingesta, and how much from the different intestinal secretions.

Contents of the Large Intestine.

When the contents of the small intestine have passed the ileo-cæcal valve, they become materially changed in their general character, partly from admixture with the secretions of this portion of the canal, and are then known as the fæces.

[1] BLONDLOT, *Traité Analytique de la Digestion*, Paris, 1843, p. 441.

The most palpable of these changes relate to consistence, color, and odor.

Fæcal matter has a much firmer consistence than the contents of the ileum; which is due to a constant absorption of the liquid portions. As a rule, the consistence is great in proportion to the length of time that the fæces remain in the large intestine; and this is variable in different persons and in the same person, in health, depending somewhat upon the character of the food.

The color changes from the yellow, more or less bright, which is observed in the ileum, to the dark yellowish-brown, characteristic of the fæces. Though the bile-pigment cannot usually be recognized by the ordinary tests, it is this which gives to the contents of the large intestine their peculiar color, which is lost when the bile is not discharged into the duodenum. In a specimen of healthy human fæces which had been dried, extracted with alcohol, the alcoholic solution precipitated with ether, and the precipitate dissolved in distilled water, we failed to detect the slightest trace of the biliary salts by Pettenkofer's test. In a watery extract of the same fæces, the addition of nitric acid also failed to show the reaction of the coloring matter of the bile.[1] The color, however, has been found to vary considerably with the diet. Wehsarg has shown that with a mixed diet, the color is yellowish-brown; with an exclusively flesh-diet, it is much darker; and with a milk-diet, it is more yellow.[2]

The odor of the fæces, which is characteristic and quite different from that of the contents of the ileum, is somewhat variable, and is due in part to the peculiar decomposition of the residue of the food, in part to the decomposition of

[1] Prof. Dalton, in comparative analyses of the contents of the small and the large intestine in dogs, in which the matters were first evaporated to dryness, the residue extracted with absolute alcohol and then precipitated with ether, always detected biliary matters by Pettenkofer's test in the contents of the small intestine, while they were invariably absent in the contents of the large intestine. (*Treatise on Human Physiology*, Philadelphia, 1864, p. 193.)

[2] *Op. cit.*

the bile, and in part to matters secreted by the mucous membrane of the colon and the glands near the anus.

The entire quantity of fæces in the twenty-four hours was found by Wehsarg to be about 4·6 ounces. This was the mean of seventeen observations; the largest quantity being 10·8 ounces, and the smallest 2·4 ounces.[1] As the average of five examinations of his own fæces on successive days, Dr. Hammond found the entire quantity in the twenty-four hours to be about 5·24 ounces.[2]

The reaction of the fæces is undoubtedly very variable, depending chiefly upon the character of the food. Marcet found the human excrements always alkaline.[3] Wehsarg, on the other hand, found the reaction generally acid, but very frequently alkaline or neutral.

The first accurate analyses of the fæces were made by Berzelius; but the great advances which have been made in physiological chemistry since that time have enabled later observers to arrive at results much more definite and satisfactory. The recent researches into the composition of the healthy fæces by Wehsarg, already referred to, have thrown much light upon the nature of the constituents derived from the food and the bile, as well as the proportions of the various inorganic salts. Marcet has lately discovered a crystallizable substance peculiar to the human fæces;[4] and we have recently shown that probably the most important excrementitious principle discharged by the rectum is derived

[1] *Op. cit.*, p. 62.

[2] HAMMOND, *Experimental Researches relative to the Nutritive Value of Albumen, Starch, and Gum, when singly and exclusively used as Food*, Philadelphia, 1857, p. 18.

[3] MARCET, *An Account of the Organic Chemical Constituents or Immediate Principles of the Excrements of Man and Animals in the Healthy State.—Philosophical Transactions*, London, 1854, p. 265.

[4] MARCET, *An Account of the Organic Chemical Constituents or Immediate Principles of the Excrements of Man and Animals in the Healthy State.—Philosophical Transactions*, London, 1854, p. 265 *et seq.*; and, *On the Immediate Principles of the Human Excrements in the Healthy State.*—Idem., 1857, p. 403 *et seq.*

from the bile, and is a peculiar modification of cholesterine.[1] Analyses of the fæces have also been made by Simon and Percy,[2] Ihring,[3] Lehmann,[4] and many others. The observations of Simon and of Ihring relate chiefly to the fæces in disease. Most of our statements concerning the composition of the fæces in health will be derived from the researches of Wehsarg and of Marcet, and our own observations.

The proportions of water and solid matter in the fæces is variable. Berzelius found in the healthy human fæces 73·3 parts of water and 26·7 parts of solid residue.[5] The average of seventeen observations by Wehsarg was precisely the same.

Dr. Hammond, in a series of observations made upon his own person for five successive days, while in perfect health, found the average proportion of water to the solid matters of the fæces to be as 730 to 270.[6] In a single specimen of perfectly healthy fæces, the entire quantity passed for the twenty-four hours (seven and a half ounces), we found the proportion of water to solid matter to be as 716 to 284.

In the observations of Wehsarg, the mean quantity of solid matter discharged in the fæces in the twenty-four hours was 463 grains; the extremes being 882·8 grains and 251·6 grains. The proportion of undigested matters in the solid residue was very small, averaging but little more than ten per cent.; the mean quantity in the twenty-four hours in ten observations being but 52·5 grains. This was found, how-

[1] *Experimental Researches into a New Excretory Function of the Liver, consisting in the Removal of Cholesterine from the Blood, and its Discharge from the Body in the Form of Stercorine (the Seroline of Boudet).—American Journal of the Medical Sciences*, October, 1862.

[2] Simon, *Animal Chemistry with Reference to the Physiology and Pathology of Man*, Philadelphia, 1846, p. 571 *et seq.*

[3] Ihring, *Mikroscopish-Chemische Untersuchungen menschlichen Faeces unter verschiedenen pathologischen Verhältnissen*, Giessen, 1852.

[4] Lehmann, *Physiological Chemistry*, Philadelphia, 1855, vol. i., p. 517 *et seq.*

[5] Berzelius, *Analyse de la Matière Excrémentitielle de l'Homme.—Annales de Chimie*, Paris, 1807, tome lxi., p. 321.

[6] Hammond, *op. cit.* The above is calculated from the results given in the table (*loc. cit.*, p. 18).

ever, to be exceedingly variable; the largest quantity being 126·5 grains, and the smallest 12·5 grains.

Microscopical examination of the fæces reveals the various vegetable and animal structures which we have referred to as escaping the action of the digestive fluids. Wehsarg also found a "finely divided fæcal matter" of indefinite structure, but containing partly disintegrated intestinal epithelium Crystals of cholesterine were never observed. Whenever the matter was neutral or alkaline, crystals of the ammonio-magnesian phosphate were found.[1] Mucus is also found in variable quantity, in the fæces, with desquamated epithelium, and a few leucocytes.

The quantity of inorganic salts in the fæces is not great. In addition to the ammonio-magnesian phosphate, phosphate of magnesia, phosphate of lime, and a small quantity of iron have been found. The chlorides are either absent or present only in small quantity.

Marcet has pretty generally found in the human fæces a substance possessing the characters of margaric acid, and volatile fatty acids; the latter free, however, from butyric acid. Cystine is mentioned as an occasional constituent.[2] He also found a coloring matter like that extracted by Verdeil from the blood and by Harley from the urine. This is probably a modification of biliverdine.

In 1854, Marcet described a new substance in the human fæces, which he called excretine, and an acid called excretoleic acid, which he supposed to be a compound of excretine. These principles and the one which we described in 1862, under the name of stercorine, are, as far as we know, the only ones which have been recognized as characteristic

[1] Wehsarg mentions amorphous fat as always found in the fæces on microscopic examination (p. 65). We have seen that the saponifiable fats cannot usually be separated from the fæces; while amorphous stercorine might easily be mistaken for fat. Wehsarg does not indicate the exact nature of the fatty matters which he observed.

[2] MARCET, *Philosophical Transactions*, 1854

of the normal fæces; and the stercorine we have found to be one of the most distinct and important of the excrementitious principles in the body.[1] The relations of excretine to the process of destructive assimilation of the tissues have not been so clearly indicated.

Excretine and Excretoleic Acid.—Excretine was obtained by Marcet from the healthy human fæces in the following way: The fæces were first treated with boiling alcohol until nothing more could be extracted. This alcoholic solution was acid and deposited a sediment on cooling. Milk of lime was then added to the solution, producing a yellowish-brown precipitate, and leaving the fluid of a clear straw-color. The precipitate was then collected on a filter, dried, afterward agitated with ether and filtered, forming a clear yellow solution. In from one to three days, beautiful long silky crystals of excretine were formed, generally collected into tufts adhering to the sides of the vessel. Examined by the microscope, these were found to consist of acicular four-sided prisms of variable size. This substance is insoluble in water, slightly soluble in cold alcohol, but very soluble in ether and hot alcohol. Its alcoholic solutions are faintly, though distinctly, alkaline. Its fusing point is from 203° to 205° Fahr. It may be boiled with potash for hours without undergoing saponification.[2] In a second paper by Marcet, published in 1857, the composition of excretine is given as $C^{78}H^{78}O^{2}S^{1}$. It was also found that its crystallization was facilitated by cold.[3] Apparently, the quantity of excretine contained in the fæces

[1] In 1833, Boudet described a new substance as existing in the serum of the blood, which he called *Séroline*. (*Nouvelles Recherches sur la Composition du Sérum du Sang.—Annales de Chimie et de Physique*, Paris, 1833, tome lii., p. 337.) This is the substance which we discovered in the fæces, and have described under the name of *Stercorine*.

[2] Marcet, *Philosophical Transactions*, 1854, p. 265 *et seq.*

[3] Excretine has not yet been made to enter into any definite combinations, and its formula is calculated on the assumption that one equivalent of excretine contains one equivalent of sulphur.

is not very great, as only 12·6 grains were obtained by Marcet from nine evacuations.[1]

We have very little definite information concerning the production of excretine. Marcet examined, on one occasion, the contents of the small intestine of a man that had died of disease of the heart, without finding any excretine.[2] It is probable that this principle is formed in the large intestine, though further observations are wanting on this point.

The substance called excretoleic acid is very indefinite in its composition and properties. It is described as an olive-colored fatty acid, insoluble in water, non-saponifiable, and very soluble in ether and in hot alcohol. It fuses at from 77° to 79° Fahr.

Stercorine.—This principle, which we discovered in the fæces in 1862, was described by Boudet in 1833, as existing in excessively minute quantity in the serum of the blood, and was called by him seroline. As we found it to be the most abundant and characteristic constituent of the stercoraceous matter, we proposed to call it stercorine;[3] particularly as our researches led us to the opinion that it really does not exist in the serum, but is formed from cholesterine by the processes employed for its extraction.

Stercorine may be extracted in the following way: The fæces are first evaporated to dryness, pulverized, and treated with ether. The ether extract is then passed through animal charcoal, fresh ether being added until the original quantity of the ether extract has passed through. It is impossible to decolorize the solution entirely by this process; but it should pass through perfectly clear and of a pale amber color. The ether is then evaporated, and the residue extracted with boiling alcohol. This alcoholic solution is evaporated, and the residue treated with a solution of caustic potash for one or

[1] MARCET, *Philosophical Transactions*, 1857, p. 410.

[2] Ibid., 1854, p. 269.

[3] *American Journal of the Medical Sciences*, October, 1862.

two hours at a temperature a little below the boiling point, by which all the saponifiable fats are dissolved. The mixture is then largely diluted with water, thrown upon a filter, and washed until the fluid which passes through is neutral and perfectly clear. The filter is then carefully dried, and the residue washed out with ether. The ether solution is then evaporated, extracted with boiling alcohol, and the alcoholic solution evaporated. The residue of this last evaporation is composed of pure stercorine.

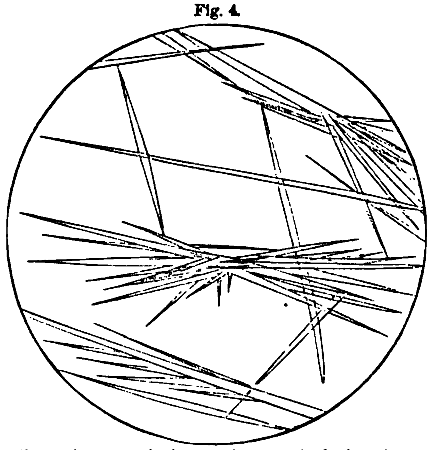
When first obtained, the stercorine is a clear, slightly amber, oily substance, about the consistence of Canada balsam used in microscopic preparations. In four or five days it begins to show the characteristic crystals. These are few in number at first, but soon the entire mass assumes a crystalline form. In one analysis we obtained from seven and a half ounces of normal human fæces (the entire quantity for the twenty-four hours), 10·417 grains of stercorine, the extract consisting of nothing but crystals. This was all the stercorine to be extracted from the regular daily evacuation of a healthy male twenty-six years of age and weighing about one hundred and sixty pounds. In the absence of other investigations, the daily quantity of this substance excreted may be assumed to be not far from ten grains.

In many regards, stercorine bears a close resemblance to cholesterine. It is neutral, inodorous, and insoluble in water and in a solution of potash. It is soluble in ether and hot alcohol, but is almost insoluble in cold alcohol. A red color is produced when it is treated with strong sulphuric acid. It may be easily distinguished from cholesterine, however, by the form of its crystals. It fuses at a low temperature, 96·8° Fahr., while cholesterine fuses at 293° Fahr.

Stercorine crystallizes in the form of thin delicate needles, frequently mixed with clear rounded globules, which are probably composed of the same substance in a non-crystalline form. When the crystals are of considerable size, the borders near their extremities are split longitudinally for a

short distance. The crystals are frequently arranged in bundles, as in Fig. 4, in which they are represented as seen under a $\frac{4}{10}$ inch objective. In Fig. 5 the crystals are represented as seen under a $\frac{1}{8}$ inch objective. These crystals cannot be confounded with excretine, which crystallizes in the form of regular, four-sided prisms, nor with the thin rhomboidal or rectangular tablets of cholesterine. They are identical with the crystals of seroline figured by Robin and Verdiel.[1]

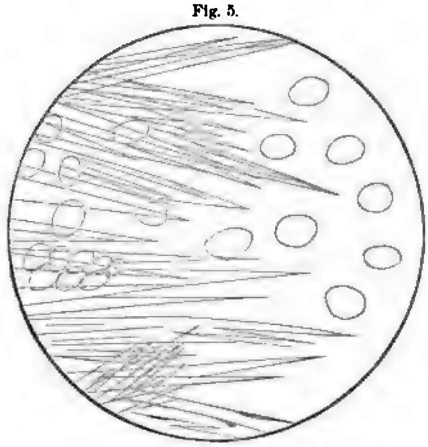
Fig. 4.



Stercorine from the human fæces, $\frac{4}{10}$ inch objective.

There can be no doubt with regard to the origin of the stercorine which exists in the fæces. We have found that whenever the bile is not discharged into the duodenum, as is probably the case, for a time, in icterus accompanied with clay-colored evacuations, stercorine is not to be discovered in the dejections. In one

Fig. 5.



Stercorine from the same specimen after it had been melted, placed upon a glass slide, covered with thin glass, and allowed to crystallize. The crystallization was very slow, occupying some weeks.

[1] Robin et Verdiel, *Chimie Anatomique*, Paris, 1853, Atlas, Pl. xxxvi., Fig. 2.

case of this kind, in which the fæces were subjected to examination, the matters extracted with hot alcohol were entirely dissolved by boiling for fifteen minutes with a solution of potash, showing the absence of cholesterine and stercorine. In another examination of the fæces from this patient, made nineteen days after, when the icterus had almost entirely disappeared and the evacuations had become normal, stercorine was discovered. Taking the estimates which have been made of the entire quantity of bile discharged into the intestine in the twenty-four hours, by Bidder and Schmidt, and Dalton, a comparison of the total quantity of cholesterine contained in the bile with the quantity of stercorine actually discharged shows a correspondence which serves as an additional argument in favor of the view that stercorine is formed from a modification of cholesterine in its passage along the intestinal canal.

These facts show conclusively that the cholesterine of the bile, in its passage through the intestine, is changed into stercorine. Both of these principles are crystalline, non-saponifiable, are extracted by the same chemical manipulations, and behave in the same way when treated with sulphuric acid. The stercorine must be regarded as a slight modification of cholesterine, the excrementitious principle of the bile.[1]

We have found that the change of cholesterine into stercorine is directly connected with the process of intestinal

[1] Our researches into the function of cholesterine have left no doubt that this is an excrementitious principle hardly second in importance to urea. We have found that cholesterine is always more abundant in the blood coming from the brain than in the blood of the general arterial system, or in the venous blood from other parts; that its quantity is hardly appreciable in venous blood from the paralyzed side in hemiplegia; and that it is separated from the blood by the liver. We have also shown that in cases of serious structural disease of the liver, accompanied by symptoms pointing to blood-poisoning, cholesterine accumulates in the blood, constituting a condition which we have called cholesteræmia. This subject will be fully discussed under the head of Excretion. For a full account of our observations upon the function of cholesterine see *The American Journal of the Medical Sciences*, October, 1862.

digestion. If an animal be kept for some days without food, cholesterine will be found in the fæces, though for a few days stercorine is also present. It is generally recognized by those who have analyzed the fæces, that cholesterine does not exist in the normal evacuations; but whenever digestion is arrested, the bile being constantly discharged into the duodenum, cholesterine is found in large quantity. For example, in hibernating animals, cholesterine is always present in the fæces.[1] The same is true of the contents of the intestines during fœtal life; the meconium always containing a large quantity of cholesterine, which disappears from the evacuations when the digestive function becomes established.

Summary.—The entire quantity of fæces passed in the twenty-four hours is from four to seven ounces. The color may be of any shade between a yellow, a yellowish-brown, and a very dark brown. The odor of the fæces is *sui generis*, and is developed only after the matters have been discharged by the ileum into the large intestine.

The reaction of the fæces may be alkaline, neutral, or acid; depending, probably, upon changes which take place in the undigested residue of the food.

The proportion of solid residue in the fæces after evaporation is about two hundred and seventy parts per thousand. The absolute quantity of solid matter discharged in the fæces in the twenty-four hours is about four hundred and sixty grains; only about ten per cent. of which consists of undigested matters.

The matters contained in the fæces which are derived from the food consist largely of vegetable structures, such as cellulose, spiral vessels, the cortex of grains, etc. The matters derived from animal food are, pieces of tendinous or elastic structure, ill-defined grumous matter, particles of muscular tissue in various stages of disintegration, the inor-

[1] MARCET, *op. cit.*,—*Philosophical Transactions*, London, 1854, p. 278.

ganic constituents of bone, etc. The fæces sometimes contain a small quantity of fatty acids.

The inorganic matters contained in the fæces consist chiefly of the phosphate of magnesia, with the phosphate of lime and a little iron. When the reaction is neutral or alkaline, crystals of the ammonio-magnesian phosphate are found. Mucus exists in the fæces in small quantity, with epithelium and a few leucocytes.

The only characteristic excrementitious constituents of the fæces which have yet been described are: stercorine, the most important excrementitious principle discharged by the rectum, and excretine and excretoleic acid, which have been found as yet only in the human fæces. Though the color of the fæces is undoubtedly due to a transformation of the coloring matter of the bile, neither the biliary salts nor biliverdine are to be detected in the large intestine by the ordinary tests. The coloring matters of the fæces resemble the coloring matters which have been extracted from the blood and the urine.

Movements of the Large Intestine.—Movements of the same general character which we have noted in the small intestine occur in the large intestine; though the peculiarities in the arrangement of the muscular fibres and the more solid consistence of the contents render these movements somewhat distinctive. In all instances where these movements have been observed in the human subject or the lower animals, they have been found to be less vigorous and rapid than the contractions of the small intestine. Indeed, when the abdominal organs are exposed, either in a living animal or immediately after death, movements of the large intestine are generally not observed, except on the application of mechanical or galvanic irritation; and they are then more circumscribed and much less marked than in any other part of the alimentary canal. In the rabbit, in which the colon is very large, the few spontaneous movements which are some-

times seen on opening the abdomen immediately after death are feeble and irregular, particularly in the cæcum. That the fæces remain for a considerable time in some of the sacculated pouches of the colon is evident from the appearance which they sometimes present of having been moulded to the shape of the canal. This appearance is frequently observed in the dejections, which are then said to be "figured."

In the cæcum, the pressure of matters received from the ileum forces the mass onward into the ascending colon, and the contractions of its muscular fibres are undoubtedly slight and ineffective. Once in the colon it is easy to see how the contractions of the muscular structure (the longitudinal bands shortening the canal, and the transverse fibres contracting below and relaxing above) are capable of passing the fæcal mass slowly onward. Though the transverse fibres are thin and seemingly of little power, they are undoubtedly powerful enough to empty the sacculi, when assisted by the movements of the longitudinal fibres, especially as the canal is never completely filled and the fæces are frequently in the form of small moulded lumps.

By these slow and gradual movements, the contents of the large intestine are passed toward the sigmoid flexure of the colon, where they are arrested until the period arrives for their final discharge. The time occupied in the passage of the fæces through the ascending, transverse, and descending colon is undoubtedly variable in different persons, as we find great variations in the intervals between the acts of defecation. During their passage along the colon, the contents of the canal assume more and more of the normal fæcal consistence and odor, and become slightly coated with the mucous secretion of the parts.

It has been pretty conclusively shown that the accumulation of fæces generally takes place in the sigmoid flexure; for under normal conditions, the rectum is found empty and contracted. This part of the colon is much more movable than

other portions, and is better calculated as a receptacle for fæces.[1] At certain tolerably regular intervals, the fæcal matter is passed into the rectum and is then almost immediately discharged from the body.

Defecation.

In health, expulsion of fæcal matters takes place with regularity generally once in the twenty-four hours. This rule, however, is by no means invariable, and dejections may habitually occur twice in the day, or every second or third day, within the limits of perfect health. It is well known that habit has a great influence upon the regularity of defecation; and sometimes, in cases of irregularity, physicians have recommended patients to make an effort to void the fæces at a certain time every day, this practice being frequently followed by the best results. At the time when defecation ordinarily takes place, a peculiar sensation is experienced calling for an evacuation of the bowels; and if this be disregarded, the desire may pass away, and after a little time, the act becomes impossible. Under these circumstances, it is probable that the fæces are passed out of the rectum by antiperistaltic action.

The condition which immediately precedes the desire for defecation is probably the descent of the contents of the sigmoid flexure of the colon into the rectum. It was formerly thought that the fæces constantly accumulated in the dilated portion of the rectum, where they remained until an evacuation took place; but the arguments of O'Beirne against such a view are conclusive. He has demonstrated by numerous explorations in the human subject, that under ordinary conditions, the rectum is contracted, and contains neither fæces nor gas. It is, indeed, a fact familiar to every surgeon that the rectum usually contains nothing which can be reached by the finger in physical examinations, and that

[1] O'Beirne, *New Views of the Process of Defecation*, Washington, 1834, pp. 11, 12.

paralysis or section of the muscles which close the anus by no means involves, necessarily, a constant passage of fæcal matter. O'Beirne not only found the rectum empty and presenting a certain amount of resistance to the passage of injected fluids, but on passing a stomach-tube into the bowel, after penetrating from six to eight inches, it passed into a space in which its extremity could be moved with great freedom, and there was instantly a rush of flatus, of fluid fæces, or of both, through the tube. In some instances in which nothing escaped through the tube, the instrument conveyed to the hand an impression of having entered a solid mass; and on being withdrawn contained solid fæces in its upper portion.[1] According to this observer, the sensation which leads to an effort to discharge the fæces is produced by the accumulation of matters in the sigmoid flexure, which finally present at the contracted portion of the rectum just at its commencement. This constriction, situated at the most superior portion of the rectum, is sometimes spoken of as the sphincter of O'Beirne.

The above is undoubtedly the mechanism of the descent of fæcal matter into the rectum in defecation, as the act is usually performed; but under certain circumstances, fæces must accumulate in the dilated portion of the rectum. Ordinarily, the discharge of fæces only takes place after the efforts have been continued for a certain time; and when the evacuation is "figured," the whole length discharged frequently exceeds so much the length of the rectum, that it is evident that a portion of it must have come from the colon. O'Beirne states, indeed, that he has frequently examined the rectum at the moment when a moderate inclination to go to stool is felt, and found it empty and contracted.[2] But in cases where the fæces

[1] O'Beirne, *op. cit.*, p. 12.

[2] O'Beirne apparently fails to make a sufficiently accurate distinction between "a moderate inclination to go to stool" (*Op. cit.*, p. 12) and the peculiar sensation which seems to demand a prompt evacuation. This latter we believe to be due to the presence of fæcal matter in the rectum.

are very fluid, or when the call for an evacuation has not been regarded and has become imperative, the immediate discharge of matters when the sphincter is relaxed shows that the rectum has been more or less distended. In many persons of constipated habit, and particularly in old subjects, the rectum may become the seat of large accumulations of hardened and impacted fæces; but this is a pathological condition.

The sensation which ordinarily precedes and gives rise to evacuation of fæcal matter is peculiar, and very variable in intensity. When this sensation is well marked but not excessive, it is probably due to the presence of fæcal matter in the rectum, not in sufficient quantity, however, to press forcibly on the sphincter. Pressure upon the rectum from any cause, or irritation of its mucous membrane, is apt to give rise to this peculiar sensation to a very marked degree. In some diseases, the exaggeration of this sensation, then called tenesmus, is very distressing.

In the process of defecation, the first act is the passage, by peristaltic contractions, of the contents of the sigmoid flexure of the colon through the slightly constricted opening of the rectum into its dilated portion below. The fæcal matter, however, is not allowed to remain in this situation, but passes into the lower portion of the rectum, in obedience to the contractions of its muscular coat, assisted by the action of the abdominal muscles and diaphragm. The circular fibres of the rectum undergo the ordinary peristaltic contraction; and the action of the longitudinal fibres is to render the rectum shorter and more nearly straight. The internal and the external sphincter present a certain amount of resistance to the discharge of the fæces, more particularly the external sphincter, which is a striated muscle of considerable power. There is always, however, a voluntary relaxation of this muscle, or rather a cessation of its semi-voluntary contraction, which immediately precedes the expulsive act. The dilatation of the anus is also facilitated by the action of the levator ani, which arises from the posterior surface of the

body and ramus of the pubis, the inner surface of the spine of the ischium, and a line of fascia between these two points, passes downward and is inserted into the median raphe of the perineum and the sides of the rectum, the fibres uniting with those of the sphincter. While this muscle forms a support for the pelvic organs during the act of straining, it steadies the end of the rectum, and by its contractions, favors the relaxation of the sphincter, and draws the anus forward.

The action of the diaphragm and the abdominal muscles is very simple. They merely compress the abdominal organs and consequently those contained in the pelvis, and assist in the expulsion of the contents of the rectum. The diaphragm is the most important of the voluntary muscles concerned in this process; and during the act of straining, the lungs are moderately filled and respiration is interrupted. The vigor of these efforts depends greatly upon the consistence of the fæcal mass, very violent contractions being frequently required for the expulsion of hardened fæces after long constipation. Though more or less straining generally takes place, the contractions of the muscular coats of the rectum are frequently competent of themselves to expel the fæces, especially when they are soft. This can be shown by arresting all voluntary muscular action during an easy act of defecation, when the fæces may be passed by contractions of the rectum alone.

By a combination of the movements above described, the floor of the perineum is pressed outward, the anus is dilated, the sharp bend in the lower part of the rectum is brought more into line with the rest of the canal, and a portion of the contents of the rectum is expelled. Very soon, however, the passage of fæces is interrupted by a contraction of the levator ani and the sphincter, by which the anus is suddenly and rather forcibly retracted. This muscular action may be effected voluntarily; but after the sphincter has been dilated for a time, the evacuation is interrupted in this way, notwithstanding all efforts to oppose it. After a time, another portion of fæces is discharged, until the matters

have ceased to pass out of the sigmoid flexure, and the rectum has been emptied. The mucous membrane of the rectum, which is rather loosely held to the subjacent tissue, is slightly prolapsed during an evacuation, but returns shortly after the act has been completed.

Very little need be said concerning the influence of the nervous system on the movements concerned in defecation. The non-striated muscular fibres which form the muscular coat of the rectum are supplied with nerves from the sympathetic system; and to the external sphincter are distributed filaments from the last sacral pair of the spinal nerves. These nerves bring the sphincter to a certain degree under the control of the will, and impart likewise the property of tonic contraction, by which the anus is kept constantly closed.

Gases found in the Alimentary Canal.

In the human subject, a certain quantity of gas is generally found in the stomach and in the small and the large intestine. The most accurate analyses of these gases, as they may be supposed to exist in the human subject in health, are those of Magendie and Chevreul, who had the opportunity of examining the bodies of several criminals immediately after execution. The previous analyses by Jurine (who was the first to examine the gases of the alimentary canal) and others, were made before the processes for the analysis of gases had been brought to a sufficient degree of perfection to insure accurate results.

The gases in the stomach appear to have no definite function. They generally exist in very minute quantity, and are sometimes absent. The oxygen and nitrogen are derived from the little bubbles of air which are incorporated with the alimentary bolus during mastication and insalivation. The other gases are probably evolved from the food during digestion; at least, there is no satisfactory evidence that they are produced in any other way.

Very little gas is ordinarily found in the stomach. Ma-

gendie and Chevreul collected and analyzed a small quantity from the stomach of an executed criminal a short time after death, and ascertained that it had the following composition: [1]

Gases contained in the Stomach.

Oxygen	11·00
Carbonic Acid	14·00
Pure Hydrogen	3·55
Nitrogen	71·45
	100·00

Magendie and Chevreul found three different gases in the small intestine. Their examinations were made upon three criminals soon after execution. The first was twenty-four years of age, and two hours before execution had eaten bread and Gruyère cheese and drunk red wine and water. The second, who was executed at the same time, was twenty-three years of age, and the conditions as regards digestion were the same. The third was twenty-eight years of age, and four hours before death, he ate bread, beef, and lentils, and drank red wine and water. The following was the result of the analyses.[2]

Gases contained in the Small Intestine.

	First Criminal.	Second Criminal.	Third Criminal.
Carbonic acid	24·39	40·00	25·00
Pure Hydrogen	55·53	51·15	8·40
Nitrogen	20·08	8·85	66·60
	100·00	100·00	100·00

No oxygen was found in either of the examinations, and the quantities of the other gases were so variable as to lead to the supposition that their proportion is not at all definite. We have already alluded to the mechanical function of these gases in intestinal digestion.[3]

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 89.
[2] Ibid., p. 115.
[3] See page 379.

In the large intestine, the constitution of the gases presented the same variability as in the small intestine. Carburetted hydrogen was found in all of the analyses. In the large intestine of the first criminal, and in the rectum of the third, were found traces of sulphuretted hydrogen. The following is the result of the analyses in the cases before cited. In the third, the gaseous contents of the cæcum and the rectum were analyzed separately.[1]

Gases contained in the Large Intestine.

	First Criminal.	Second Criminal.	Third Criminal.	Third Criminal.
			Cæcum.	Rectum.
Carbonic Acid[2].....	43·50	70 00	12·50	42·86
Carburetted hydrogen and traces of sulphuretted hydrogen	5·47	....	....	....
Pure hydrogen and carburetted hydrogen.............	....	11·60	....	11·18
Pure hydrogen......	....	....	7·50	....
Carburetted hydrogen	....	....	12·50	....
Nitrogen...........	51·03	18·40	67·50	45·96
	100·00	100·00	100·00	100·00

Origin of the Intestinal Gases.—With our present information on this subject, the most reasonable view to take of the source of the gases normally found in the intestines is that they are given off from the articles of food in their various stages of digestion and decomposition. That this is the principal source of the intestinal gases there can be no doubt; and it is well known that certain articles of food, particularly vegetables, generate much more gas than others. The principal gases found in the intestinal canal may all be obtained from the food; while some of them, as hydrogen and carburetted hydrogen, do not exist in the blood; and it is difficult to conceive how they can be generated in the in-

[1] MAGENDIE, *op. cit.*, p. 128.

[2] In this examination, "traces of sulphuretted hydrogen were manifested upon the mercury before the instant when the gas was analyzed;" (*op. cit.*, p. 129).

testine except by decomposition of some of the articles of food. Hydrogen and its compounds are always found in quantity in the small and the large intestine. Chevillot, who made a number of researches into the composition of the gases of the alimentary canal in patients dead from different diseases, submitted various alimentary substances taken from the digestive organs to a temperature equal to that of the body. In a certain number of instances, but not in all, hydrogen was evolved.[1]

It is said that gas is sometimes found in the intestines of the fœtus, and that it may be generated in a loop of intestine in a living animal, after a portion of the canal has been drawn out, isolated by ligature, freed from its liquid and gaseous contents, and returned to the abdomen. In some diseased conditions also, it is very common for the abdomen to become rapidly tympanitic, the gas being generated so quickly that its presence is not easily explained by supposing it to be evolved by decomposition of the ingesta. It has, indeed, been supposed that the intestinal mucous membrane is capable of secreting gases as well as liquids; but in support of this view there does not appear to be any positive demonstration. No doubt some of the gases which may be formed in the intestine are capable of absorption. It is impossible to say, however, that even the gases normally held in solution in the blood, namely, oxygen, nitrogen, and carbonic acid, are exhaled from the blood into the intestinal cavity. Oxygen is never given off in this way, for this gas has only

[1] CHEVILLOT, *Recherches sur les Gaz de l'Estomac et des Intestins de l'Homme à l'état de maladie.—Journal de Physiologie*, Paris, 1829, tome ix., p. 310. Magendie (*Précis Élémentaire de Physiologie*, Paris, 1836, p. 117) states that Chevillot collected the contents of the small intestine, which he allowed to ferment for a certain time at the temperature of the body, obtaining exactly the same gases which were found in the intestine. The reference to the paper of Chevillot is given above, and it is there simply stated that hydrogen is sometimes given off from the contents of the small intestine. Chevillot proposed at some future time to give the full results of his experiments on this subject, but as far as we know, this has never been done.

been found in the stomach, and is there derived from air which has been swallowed. With regard to the origin of the other gases found in the intestine under the peculiar circumstances just mentioned, in which they are apparently generated with much rapidity, there are not sufficient data to enable us to form an intelligent opinion.

CHAPTER XV.

ABSORPTION.

General considerations—Absorption by blood-vessels—Absorption by lacteal and lymphatic vessels—Physiological anatomy of the lacteal and lymphatic system—Thoracic duct—Structure of the lacteal and lymphatic vessels—Lymphatic glands—Absorption of albuminoids by the lacteals—Absorption of glucose and salts by the lacteals—Absorption of water by the lacteals—Absorption from parts not connected with the digestive system—Absorption from the skin—Absorption from the respiratory surface—Absorption from closed cavities, reservoirs of glands, etc.—Absorption of fats and insoluble substances—Variations and modifications of absorption—Influence of the condition of the blood and the vessels on absorption—Influence of the nervous system on absorption.

Digestion has two great objects: one is to reduce the different alimentary principles to a fluid condition, and the other to commence the series of catalytic transformations by which these principles are rendered capable of nourishing the organism. The principles thus acted upon are taken into the blood as fast as the requisite changes in their constitution are effected; and once received into the circulation, become part of the great nutritive fluid, supplying the waste which the constant regeneration of the tissues from materials furnished by the blood necessarily involves. The only group of principles which does not obey this general law is the fats. Though a small portion of the fat taken as food passes directly into the blood-vessels of the intestinal canal, by far the greatest part finds its way into the circulation by means of special absorbent vessels which empty into large veins. In whatever way fat enters the blood, it is never dissolved, but is reduced to the condition of a fine emulsion.

The process by which digested materials are taken into the blood is called absorption. It is now recognized that two sets of vessels are concerned in the performance of this function; namely, the blood-vessels and the lacteals. Those parts of the food which have been rendered fluid and are capable of forming a homogeneous mixture with the blood-plasma are absorbed chiefly by the blood-vessels, though a small portion finds its way into the lacteals. The emulsified fats are taken up in greatest part by the lacteals, though a small quantity is taken directly into the blood. In treating of this subject, it will be convenient to consider the action of these two kinds of vessels separately.

Absorption by Blood-Vessels.

That soluble substances can pass through the delicate walls of the capillaries and small veins and that absorption actually takes place in great part by blood-vessels is a fact which hardly demands discussion at the present day. There are now all the proofs that could be asked in support of this view. Soluble principles which have disappeared from the alimentary canal have been repeatedly found in the blood coming from the part, even when the lymphatics have been divided and communication existed only through the blood-vessels. The old theoretical view which was entertained before the lymphatics and lacteals were discovered was that absorption took place by blood-vessels; but after special absorbent vessels were described, it was generally supposed that they furnished the only avenue for the entrance of new matters into the economy, though the doctrine of vascular absorption was retained by a few.[1] It was only after the

[1] The observations of William and John Hunter, who attempted to show by experiments upon living animals that the lacteals were the only absorbent vessels of the intestines, have been so completely disproved by more recent investigations that they do not demand extended discussion. These experimenters showed that milk introduced into the intestinal cavity was absorbed by the lacteals and not by the veins; but the evidence that absorption of other fluids did not take place by the veins was entirely insufficient. The experiments referred

conclusive experiments of Magendie, in 1809, that positive proof was given of the absorbing power of the blood-vessels. These experiments settled the question of vascular absorption, though they led some to take too exclusive a view of the importance of the venous radicles in this function, and to deny that absorption took place to any considerable extent through the lymphatic and lacteal system.

If it were consistent with the plan of this work to enter into a purely historical discussion of the theories which have been advanced from time to time concerning the mechanism of absorption, it might be shown that comparatively modern researches have led us back to the views entertained by the ancients, before the discovery of the lymphatic system of vessels; but we shall confine ourselves to a history of those facts connected with absorption, which have been experimentally demonstrated. In 1808, in a paper on the "Structure and Uses of the Spleen," read before the Royal Society of London, Everard Home showed that various matters injected into the stomach were carried to the spleen without passing into the thoracic duct. The inference to be drawn from this paper, which is very brief, is that he supposed that these substances were carried to the spleen by absorbents, and were there mixed with the blood. In these experiments Home was assisted by Brodie.[1] In 1811, as the result of further experiments on this subject, Home abandoned the idea that the principles absorbed were mixed with the blood in the spleen, as he found that matters injected into the stomach appeared in the blood in a dog from which the spleen had been removed four days before.[2] The first

to were made in 1758 and 1759. (J. HUNTER, *Observations on Certain Parts of the Animal Œconomy*, Philadelphia, 1840, p. 303.)

[1] HOME, *On the Structure and Uses of the Spleen.—Philosophical Transactions*, London, 1808, p. 45 *et seq.*

[2] HOME, *Experiments to prove that Fluids pass directly from the Stomach to the Circulation of the Blood, and from thence into the Cells of the Spleen, the Gall-Bladder and Urinary Bladder without going through the Thoracic Duct.—Philosophical Transactions*, London, 1811, p. 163 *et seq.*

of these essays contained very little concerning the general process of absorption from the alimentary canal, but was supposed to throw some light upon the function of the spleen, as an organ in which part of the chyle was mixed with the blood. The second essay was published two years after the researches of Magendie had been communicated to the Institute of France.

The results of the experiments of Magendie were of the most positive character.[1] In his first experiments, it was found that after ligation of the thoracic duct in dogs, poisoning by a solution of upas introduced into the peritoneal cavity, the pleural cavity, the stomach, intestines, or muscles of the thigh, took place with no diminution in intensity or rapidity. The second series of experiments was even more striking. The abdomen of a dog, that had eaten largely seven hours before, was opened, and a loop of the small intestine drawn out. About fifteen inches of the canal was separated from the rest by two ligatures, and finally cut off beyond them. The lymphatics arising from the isolated portion of the intestine, which were very apparent, were all tied with two ligatures, and divided between them. Five mesenteric arteries and five veins then remained connecting the intestine with the vascular system. Four of the arteries and veins were ligated and divided; and the single artery and vein which remained were isolated for about two inches of their length, and even the cellular coat dissected off, for fear that it might be said to contain lymphatics. A small quantity of upas was then introduced into the isolated portion of the intestine (which had no communication with the body except by the single mesenteric artery and vein), the loop was enveloped in a fine cloth and returned to the abdominal cavity. In about six minutes, the general effects of the poison were manifested with their usual intensity. This experiment was repeated several times,

[1] MAGENDIE, *Mémoire sur les Organes de l'Absorption chez les Mammifères; lu à l'Institut le 7 août*, 1809.—*Journal de Physiologie*. Paris, 1821, tome i., p. 18 *et seq.*

with the same result. In other experiments, the leg was separated from an animal, all the parts being divided except the crural artery and vein; and in one experiment, a quill was introduced into each of these vessels, secured with ligatures, and the vessels themselves divided, so that there could be no communication of the leg with the body except through the circulating blood. Under these conditions, the poison introduced into the foot produced its effects upon the system in ordinary time; while it was found that the effects of the poison could be retarded or arrested by simple compression of the vein. These experiments, which are models of ingenuity and accuracy, removed all doubt of the fact that absorption takes place by blood-vessels.

Most of the experiments which followed those of Magendie simply confirmed his results. Tiedemann and Gmelin, as the result of a very elaborate series of investigations, showed that alimentary matters, odorous and coloring matters, and various saline and metallic substances, when taken into the alimentary canal, find their way into the system by the absorbents and the thoracic duct, and by the radicles of the portal vein.[1] Finally, Ségalas, in 1822, supplied about the only link wanting in the chain of evidence developed by the original experiments of Magendie. He demonstrated that poisoning did not follow the introduction of a solution of nux vomica into a loop of intestine separated from the rest of the canal, so long as the circulation was interrupted, or when the blood returning from the part by the vein was discharged from the vessel and not carried into the general circulation.[2]

At this time the subject of vascular absorption attracted a great deal of attention among experimental physiologists; and a committee, consisting of Drs. Harlan, Lawrence, and

[1] TIEDEMANN ET GMELIN, *Recherches sur la Route qui prennent diverses Substances pour passer de l'Estomac et du Canal Intestinal dans le Sang; sur la Fonction de la Rate et sur les Voies cachées de l'Urine*, Trad. par S. Heller, Paris, 1821.

[2] SÉGALAS, *Note sur l'Absorption Intestinale.—Journal de Physiologie*, Paris, 1822, tome ii., p. 117 *et seq.*

Coates, was appointed by the Academy of Medicine, of Philadelphia, to examine into the subject. This committee made a great number of experiments, which entirely confirmed the observations of Magendie.[1] The same may be said of the experiments of Panizza, which were, indeed, as regards intestinal absorption, little more than a repetition of those of Magendie and Ségalas.[2] At the present day there is no difference of opinion among physiologists concerning the direct absorption of nutritive matters by the blood-vessels of the alimentary canal. It has been repeatedly shown, indeed, that during absorption, the blood of the portal vein is rich in albuminoids, sugar, and other principles resulting from digestion.

In the mouth and œsophagus, the sojourn of alimentary principles is so brief, and the changes which they undergo so slight, that no absorption of any moment can take place. It is evident, however, that the mucous membrane of the mouth is capable of absorbing certain soluble matters, from the effects which are constantly observed when the smoke or the juice of tobacco is retained in the mouth even for a short time. In the stomach, however, the absorption of certain materials takes place with great activity. A large proportion of the ingested liquids,[3] and of those principles of food which are dis-

[1] *Report of the Committee of the Academy of Medicine of Philadelphia, on the means by which Absorption is effected.—Philadelphia Journal of the Medical and Physical Sciences*, 1821, vol. iii., p. 273, and 1822, vol. v., p. 327.

[2] PANIZZA, *De l'Absorption Veineuse*, Paris, 1843. The most striking of the experiments of Panizza was one made on a horse, in which a loop of the small intestine was drawn out, isolated by ligatures, and left connected with the system only by a single artery and vein. Poisons and other substances introduced into this loop were detected in blood taken from the vein, and their effects upon the system were not manifested so long as the blood coming from the part was prevented from entering the general circulation. (*Op. cit.*, p. 19.)

[3] It has been repeatedly demonstrated by experiments that liquids are absorbed from the stomach after the pylorus has been tied. This has been done by Magendie (*Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 140), by Bouchardat and Sandras, and others. The experiments made by Colin and Bouley on absorption from the stomach after ligation of the pylorus in

solved by the gastric juice and converted into albuminose, is taken up directly by the blood-vessels of the stomach. It may, indeed, be assumed as a general law, that digested matters are in great part absorbed as soon as their transformations in the alimentary canal have been completed.

In the passage of the food down the intestinal canal, as we have already seen, there is a constant loss of material. As the digestion of the albuminoids is completed, these principles are absorbed, and their passage into the mass of blood is indicated chiefly by an increase in its proportion of albumen. Analyses by Béclard of blood taken from the portal veins during digestion have shown a great increase in the proportion of fibrin over the blood in other parts of the venous system and in the same vessel during the intervals of digestion.[1] These observations have been repeatedly confirmed, and many of the other products of digestion, such as glucose and fatty emulsion, have also been demonstrated in quantity in the blood of the portal vein during absorption. The fats, though taken up in greatest part by the lacteals, are always found in greater or less quantity in the portal blood. It has frequently been observed that after a full meal consisting largely of fat, the blood from the portal vein, as it cools and coagulates, leaves a white scum of fat upon the surface.[2] On one occasion we observed in the portal blood of an animal killed in full digestion a layer of fat on cooling so thick that a quantity of blood, which was spilled upon a table and the

different animals show that in the carnivora, and in most animals with a single stomach, this takes place with great rapidity. In the horse, the mucous membrane of a great portion of the stomach is lined by pavement epithelium like that found in the œsophagus, and absorption from the stomach is very slow. (COLIN, *Traité de Physiologie Comparée*, Paris, 1856, tome ii., p. 29 *et seq.*

[1] BÉCLARD, *Recherches Expérimentales sur les Fonctions de la Rate et sur celles de la Veine Porte.—Archives Générales de Médecine*, Paris, 1848, p. 443.

[2] Bernard found in the dog that the portal blood sometimes contained almost as much fatty emulsion as the chyle (*Du Rôle de l'Appareil Chylifère dans l'Absorption des Substances Alimentaires*).—*Comptes Rendus*, Paris, 1850, tome xxxi., p. 802.

floor, was white, like milk. We have since frequently attempted to demonstrate this excessively chylous condition of the blood during the absorption of fats, but have found that it is not generally so well marked.

The greatest part of the food is absorbed by the intestinal mucous membrane, and, with the alimentary substances proper, a large quantity of secreted fluid is reabsorbed. This fact is particularly striking as regards the bile. The biliary salts disappear as the alimentary mass passes down the intestine and are undoubtedly absorbed, though they are so changed that they cannot be detected in the blood by the ordinary tests. In this portion of the alimentary canal, it will be remembered that an immense absorbing surface is provided, by the arrangement of the mucous membrane in folds, forming the valvulæ conniventes, and the presence of the innumerable villi which are found throughout the small intestine. A certain portion of the gaseous contents of the intestines is also absorbed, though it is not easily ascertained what particular gases are thus taken up.[1]

Absorption by Lacteal and Lymphatic Vessels.

The history of the discovery of what is ordinarily termed the absorbent system of vessels, from the vague allusions of Hippocrates, Galen, Aristotle, and others, to the description of the thoracic duct in the middle of the sixteenth century by Eustachius,[2] and finally to the discovery of the lacteals by Asellius, in 1622, is more interesting in an anatomical,

[1] In treating of digestion, we have necessarily considered the complete preparation of alimentary principles for absorption, and have frequently alluded to the fact that these principles are taken up as fast as they are thus modified. In connection with the subject of absorption, therefore, it will be only necessary to point out the vessels which are concerned in this function, and the mechanism of the passage of liquids through their walls.

[2] BARTHOLOMÆUS EUSTACHIUS, *De Vena quæ Azygos Græcis dicitur*, etc. (*Opuscula Anatomica*, Venetiis, 1564, p. 301). Eustachius discovered in the horse a vessel beginning at the left jugular vein and descending toward the pillars of the diaphragm, which he described as "always white, and filled with watery humor." This was the thoracic duct.

than in a physiological point of view. Our knowledge of the anatomy of the absorbent system dates from the discovery of the thoracic duct; but from the discovery of the lacteals, dates the history of these vessels as the carriers of nutritive matters from the intestinal canal to the general system.

In 1622, in making an experiment on a dog for the purpose of demonstrating to some scientific friends certain points connected with the functions of the recurrent laryngeal nerves, Asellius opened the abdomen and saw for the first time little white vessels passing back from the intestine between the folds of the mesentery. Not knowing at first the nature of these vessels, he punctured one of them, and the milky fluid escaped, revealing their true character.[1] The discovery of the lacteal system was thus made apparently by pure accident. The entire history of this discovery is given by its author. He states that when the dog died, the white vessels disappeared from before his eyes. The following day, on opening the abdomen of another dog, he found no lacteals; but remembering that the first animal had been experimented upon while in full digestion, he exposed the abdominal organs in another dog under the same conditions, and again found the vessels full of chyle. His observations upon dogs were afterward confirmed by experiments upon cats, sheep, and many other animals. Asellius died in 1626, and it was reserved for others to complete his discovery by showing the true course of the lacteals; he supposing that they passed directly to the liver, where the chyle was made into blood. His work, *De Lactibus sive Lacteis Venis*, was published in 1628,[2] by Tadinus and Sep-

[1] GASPAR ASELLIUS, *De Lactibus sive Lacteis Venis*, etc., Basileæ, Typis Henric-Petrinis, 1628, p. 19 *et seq.*

[2] The copy of Asellius in our possession was published by Alexander Tadinus and Senator Septalius, and bears the date of 1628. Reference to the same work, published in 1627, at Mediol, is made by Bérard (*Cours de Physiologie*, Paris, 1849, tome ii., p. 563).

talius, two of his friends who were present at his first demonstration:[1]

Like many great discoveries, the demonstration of the lacteals was denied by several of the prominent physiologists of the day. Among others, Harvey is frequently quoted as refusing to recognize the claims of Asellius; a want of appreciation of the claims of another to an important discovery, which might justly be regarded as ungenerous in so great a discoverer, and one who suffered so keenly from similar opposition. We do not find, however, that this subject is discussed to any extent in the systematic works of Harvey; but it is mentioned in letters written during the later periods of his life. In one of these, addressed to Dr. Morison, of Paris, in 1652, in speaking of the discovery by Asellius and the later discovery of the connection between the lacteals and the thoracic duct by Pecquet, Harvey, while admitting the existence of the vessels, does not acknowledge that they carry the chyle from the intestine.[2] In another letter, written in 1655, he excuses himself from investigating the subject of the use of these vessels on account of his advanced age, "which unfits us for the investigation of novel subtleties, and the mind which inclines to repose after the fatigue of lengthened labors."[3] At the time when the first letter was written, Harvey was seventy-four years of age, and he was seventy-seven at the date of the second letter. The positive proof of the connection of the lacteals with the thoracic duct was only published in 1651, and the work reached Harvey just before the letter to Dr. Morison was written. It is not to be expected that Harvey would at that time attempt

[1] It is stated by Breschet that in 1628, the lacteals were seen for the first time in the human subject. The body of a criminal, who had made a copious repast before his execution, was given by Peiresc, senator of Aix, to Gassendi, and some physicians of his acquaintance, who made an examination an hour and a half after death and found the vessels full of chyle. (BRESCHET, *Système Lymphatique*, Paris, 1836, p. 4.)

[2] HARVEY, *Works*, Sydenham edition, London, 1847, p. 604 *et seq.*

[3] Ibid., p. 613 *et seq.*

with all the ardor of youth, to verify new experiments, and his disinclination to do so should not be regarded, as it seems to be by some, as a blot upon his reputation.

In 1649,[1] Pequet discovered the receptaculum chyli, and demonstrated that the lacteals did not pass to the liver, but emptied the chyle into the commencement of the thoracic duct, by which it was finally conveyed into the venous system.[2] In 1650–'51, the anatomical history of the absorbent vessels was completed by the discovery, by Rudbeck, of vessels carrying a colorless fluid, in the liver, and finally in almost all parts of the body. Rudbeck demonstrated the anatomical identity of these vessels with the lacteals.[3] They were afterward carefully studied by Bartholinus, who gave them the name of lymphatics.[4]

It is unnecessary to follow out the various researches made into the structure of the lymphatics in man and the inferior animals by the Hunters, Hewson, Monro, Cruik-

[1] 1649 is given by Haller as the date of this discovery (*Elementa Physiologiæ*, Bernæ, 1765, tomus vii., p. 203). Some authors state that the discovery was made in 1647, and others in 1648. The original work of Pequet was published in 1651. He does not himself give the date of the discovery, though he states that the investigations which formed the basis of his work occupied three years.

[2] J. PEQUETUS, *Experimenta nova Anatomica*, etc., in the *Bibliotheca Anatomica* by CLERICUS and MANGETUS, Genevæ, 1699, tomus ii, p. 689 *et seq.*

[3] OLAÜS RUDBECK, *Nova Exercitatio Anatomica, exhibens Ductus Hepaticos Aquosos et Vasa Glandularum Serosa*, in the *Bibliotheca Anatomica*, tomus ii., p. 729 *et seq.*

[4] BARTHOLINUS, *Vasorum Lymphaticorum Historia nova*, in the *Bibliotheca Anatomica*, tomus ii., p. 722. The honor of the discovery of the lymphatics is by some claimed for Bartholinus. His observations, however, were made in 1651–'52, while those of Rudbeck were made in 1650–'51.

Some authors have advanced the claims of Dr. Jolyffe, an English anatomist, to the discovery of the lymphatics. In Cruikshank's elaborate work (*The Anatomy of the Absorbing Vessels in Man*, second edition, London, 1790, p. 36), it is stated that in 1653, Dr. Jolyffe, who was then taking his degree at Cambridge, informed Glisson that he had discovered a fourth variety of vessels, different from the veins, arteries, and nerves. This was two years later than the discovery of these vessels by Rudbeck; and it is evident that Jolyffe, who made no publication of his observations at the time, has no claim to priority, though he may have been ignorant of the observations of his predecessors.

shank, and others. Though these vessels are very delicate and difficult of study, it is now pretty generally admitted that they have no orifices at their origin in the intestines and other parts, but are perfectly closed, and all substances which are absorbed by them enter by imbibition. The old idea, which dates from the discoveries of Asellius and Pecquet, that the lacteals absorb all the products of digestion, was overthrown by the experiments of Magendie, and of those who experimented after him on vascular absorption. It is now known that the fatty portions of the food, reduced to a very fine emulsion by the pancreatic juice, are absorbed by this system of vessels, and that these are the only principles which are taken up in great quantity. The arguments which we have already mentioned are sufficient to establish this fact. If the abdomen of a living animal be opened during full digestion, then, and then only, will the lacteals and the thoracic duct be found distended with fatty emulsion. If the organ which digests fat be rendered incapable of performing its function, the lacteals cease to carry chyle. These vessels do not appear in the mesentery until the food has passed the orifice of the pancreatic duct. Finally, the observations of Bouchardat and Sandras remove all doubt as to the absorption of the products of the digestion of fatty matters by the lacteals; for these observers found not only that in dogs the proportion of fat in the chyle was increased *pari passu* with an increase in the quantity of fat taken as food, but that the particular kinds of fat administered to the animals could be recognized in the chyle.[1] We have seen that a certain quantity of fat escapes the lacteals and is absorbed directly by the blood-vessels; and it becomes an important question to determine whether the lacteals, in addition to their more prominent function, be not concerned in the absorption of drinks, the albuminoids, saline and saccharine matters, etc. This question will be taken up

[1] BOUCHARDAT ET SANDRAS, *Recherches sur la Digestion et l'Assimilation des Corps gras.—Annuaire de Thérapeutique*, Paris, 1845, p. 242 *et seq.*

after the consideration of certain points in the anatomy of the lymphatic system.[1]

Physiological Anatomy of the Lacteal and Lymphatic System.—One of the most difficult problems in anatomy is to determine the situation and mode of origin of the lymphatics in different parts of the body. The tenuity of the walls of these vessels, even in their course, and the presence of innumerable valves, render it impossible to study them by the ordinary methods of injection. Since it has been ascertained, however, that they originate in many parts by a rich anastamosing plexus, their anatomy has been well made out in certain situations by simply puncturing with a fine-pointed canula the parts in which the plexus is supposed to exist, and allowing a fluid, generally mercury, to gently diffuse itself in the vessels of origin. Following the course of the vessels, the fluid passes into the larger trunks, and thence to the lymphatic glands. The regularity of the plexus through which the fluid is first diffused and the passage of the injection through the larger vessels to the glands are positive proof that the lymphatics have been penetrated, and that the appearances observed are not the result of mere infiltration. This mode of investigation is best illustrated in the injection of the lymphatics of the skin. The pressure employed is derived simply from a column of mercury of sufficient height; the tube in which the mercury is contained being connected with a flexible tube, by which the height may be readily in-

[1] One of the most successful of the early investigators into the anatomy of the lymphatic system was the great anatomist, Mascagni. He demonstrated the capillary plexus of origin of these vessels in many of the tissues of the body, but was led into the error, in some instances, of supposing that fluid simply extravasated in the substance of the tissue was contained in lymphatic vessels. He has therefore described lymphatics in situations where they have not been demonstrated by more recent investigations. However, the figures which he gives of these vessels are copied into many of the recent works on anatomy. (MASCAGNI, *Dei Vasi Linfatici.—Prodromo della Grande Anatomia*, Firenze, 1819, pp. 3–54.)

creased or diminished at will. With the flexible tube is connected the capillary tube of glass, which is to be introduced into the part to be injected. In the case of the skin, the fine glass point is introduced just below the cuticle at so acute an angle as to be almost horizontal. A stop-cock, which is connected with a tube into which the glass point is fitted, is then turned, and the pressure of the column of mercury forces in the injection. The puncture in the skin is to be very superficial, otherwise the mercury will pass into the blood-vessels. When the operation has been successful, the mercury will be seen to "cover the skin with a silvery net-work." The tube should remain in place for from half a minute to a minute only. To demonstrate that this plexus really consists of lymphatic vessels, one of them may be denuded and punctured with the glass point, when the lymphatic will become instantly distended as far as the nearest gland, in which the injection is always arrested.[1]

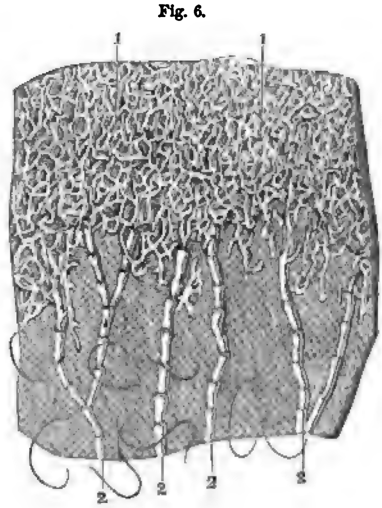
Lymphatics have not been actually injected and demonstrated in all the tissues of the body; but in some parts in which it has been thus far impossible to inject them, we are not justified in assuming positively that they do not exist. For example, in the intestinal villi, according to Sappey, these vessels have never been seen, though their existence is almost certain. The most generally received views with regard to the ordinary mode of origin of the lymphatic vessels is that they commence by a closed capillary plexus, which does not communicate with either the small arteries, veins, or the capillary blood-vessels, and is always situated externally to the blood-vessels. It does not appear that the vessels composing this plexus vary much in size. They are very elastic, and after distension by injection, they return to a very small diameter when the fluid is allowed to escape. It is prob-

[1] For full details for the performance of these exceedingly delicate manipulations, the reader is referred to the work of Sappey. (*Traité d'Anatomie Descriptive*, Paris, 1853, tome i., p. 639 *et seq.*) This author has been peculiarly successful in his researches into the minute anatomy of the lymphatic system.

able, therefore, that the capacity of the vessels is much exaggerated by the means which are taken to render them apparent. In some recent observations by Dr. Belaieff, of St. Petersburg, into the origin of the lymphatics of the penis, the walls of the vessels were rendered apparent by the action of nitrate of silver in solution in pure water, and it is probable that they were very little distended. The smallest of these vessels had a diameter of about $\frac{1}{300}$ of an inch.[1] This may be taken as their average diameter in the primitive plexus. This plexus, when the vessels are abundant, as they are in certain parts of the cutaneous surface, resembles an ordinary plexus of capillary blood-vessels, except that the walls of the vessels are thinner and their diameter is greater.

In a recent work on the lymphatic system, by Dr. Labéda, which seems to represent the latest ideas of the French school,[2] it is stated, on the authority of Robin (whose observations are said to have been confirmed by His), that the vessels of origin of the lymphatic system are always applied in the form of a half-cylinder upon the capillary blood-vessels "in such a manner that the wall of the capillary forms one wall of the lymphatic: they do not pass along the veins, but along the arte-

Fig. 6.



1.1. Deep or subdermic net-work of lymphatics of the skin.—2.2.2.2. Vessels branching from this net-work and applied to the internal face of the integument, from which they soon extend and pass into the substance of the subcutaneous cellulo-adipose layer. (SAPPEY, *Manuel d'Anatomie Descriptive*, Paris, 1847, tome i., p. 598.)

[1] BELAIEFF, *Recherches Microscopiques sur les Vaisseaux Lymphatiques du Gland.—Journal de l'Anatomie et de la Physiologie*, Paris, 1866, tome iii., p. 469.

[2] LABÉDA, *Système Lymphatique*, Paris, 1866.

rioles, and apply themselves indistinctly in the form of a concentric *demi-canal* upon each capillary, then the lymphatic is detached little by little from the vessel which it accompanies, and possesses a proper individuality (*autonomie*) (*Cours de* CH. ROBIN)."[1] Robin alludes to this as the general mode of origin of the lymphatics, and mentions "the impossibility of capillary rupture or capillary exosmosis without communication with the lymphatics when they exist."[2] But in a recent publication on the lymphatic system of the torpedo, he describes this disposition of the lymphatics around the small arteries, in fishes, reptiles, and batrachians, without applying it distinctly to the human subject.[3] Robin has described a peculiar mode of origin in the lymphatics of the brain and spinal cord, which will be referred to in connection with the mode of origin of the lymphatics in particular parts.

In the general description of the lymphatic system, three sets of vessels are usually recognized: the plexus situated on the general surface; the deep vessels; and those coming from the small intestine, ordinarily called lacteals.

The superficial vessels have the smallest diameter, and are by far the most numerous. They are composed of the fine plexus already mentioned, very superficially situated in the skin, and a second plexus just below the skin, composed of vessels of much greater diameter. The skin is thus enclosed, as it were, between two plexuses of capillary lymphatics. A plexus analogous to the most superficial plexus of the skin is found just beneath the surface of the mucous membranes. These may, indeed, be classed with the superficial lymphatics.

The deep lymphatics are much larger and less numerous, and their origin is less easily made out. These accompany

[1] LABÉDA, *op. cit.*, p. 27.

[2] ROBIN, *Programme du Cours d'Histologie*, Paris, 1864, p. 210.

[3] ROBIN, *Mémoire sur l'Anatomie des Lymphatiques des Torpilles.—Journal de l'Anatomie et de la Physiologie*, Paris, 1867, tome IV., p. 3 *et seq.*

the deeper veins in their course. They receive the lymph from the superficial vessels.

No valvular arrangement is found in the smallest lymphatics; but the vessels coming from the primitive plexuses, and the large vessels, contain valves in immense numbers. These valves, being so closely set in the vessels, give to them, when filled with injection, a peculiar and characteristic beaded appearance.

The course of the lymphatics is generally tolerably direct. As they pass toward the great trunks by which they communicate with the venous system, they present a peculiar anastomosis with the adjacent vessels, called anastomosis by bifurcation; that is, as a vessel passes along with other vessels nearly parallel with it, it bifurcates, and the two branches pass into the nearest vessels on either side. These anastomoses are quite frequent and generally occur between vessels of equal size. In their course, the vessels pass through the lymphatic glands, which will be described further on.

A notable peculiarity in the lymphatic vessels is that they vary very little in size, being nearly as large at the extremities as they are near the trunk. In their course, they are always much smaller than the veins and do not progressively enlarge as they pass on to the great lymphatic trunks. The largest-sized vessels as they pass from the skin are from $\frac{1}{25}$ to $\frac{1}{12}$ of an inch in diameter,[1] and the larger vessels, in their course, have a diameter of from $\frac{1}{12}$ to $\frac{1}{8}$ of an inch.[2] As in the case of the smallest lymphatics in the primitive plexus, the elasticity of the walls of the vessels renders their calibre greatly dependent upon the pressure of fluid in their interior. Many anatomists have noticed that vessels hardly perceptible while empty are capable of being dilated to the diameter of half a line or more, returning to their original size as soon as the distending fluid is removed.[3]

[1] BELAIEFF, *op. cit.*

[2] KÖLLIKER, *Manual of Human Miscroscopic Anatomy*, London, 1860, p. 508.

[3] MILNE-EDWARDS, *Leçons sur la Physiologie*, Paris, 1859, tome iv., p. 509, note.

The peculiarities which the lymphatics present in the different tissues and organs do not possess much physiological interest, except the arrangement of the vessels of origin in the substance of the brain and spinal cord. In the skin, the only interesting peculiarity which we have not already noticed is that the vessels appear to be very unequally distributed in different parts of the surface. According to Sappey,[1] they are particularly abundant in the scalp over the biparietal suture, the soles of the feet and the palms of the hand, the fingers at the lateral portion of the last phalanges, and the scrotum. In the median portion of the scrotum, they attain their highest degree of development. They are also found, though in fewer numbers, originating from around the median line on the anterior and posterior surface of the trunk; the posterior median portion of the extremities; the skin over the mammæ; and around the orifices of the mucous passages. Sappey has injected lymphatic vessels in the anterior portion of the fore-arm, the thigh, and the leg, and the middle portion of the face, though they are demonstrated with difficulty in these situations. If they exist at all in other portions of the cutaneous surface, they are few in number and rudimentary.

In the mucous system, the lymphatics are very abundant. Here are found, as in the skin, two distinct layers which enclose between them the whole thickness of the mucous membrane. The more superficial of these layers is composed of a rich plexus of small vessels, and beneath the mucous membrane is a plexus consisting of vessels of larger size and less numerous. The superficial plexus is exceedingly rich in the mixed structure which forms the lips and the glans penis, and around the orifices of the mouth, the nares, the vagina, and the anus. There are certain mucous membranes in which the lymphatics have never been injected. These are the mucous membrane of the bronchial tubes, the membrane lining all of the ducts of the glands except the ureters, the Schneide-

[1] *Op. cit.*

rian mucous membrane, and the conjunctiva. When an injection has appeared to penetrate in these situations, it was probably a mere infiltration of the parts, as the fluids never have been made to enter the larger vessels, much less pass to a lymphatic gland.[1]

In the visceral layer of the serous membranes, the lymphatics have been demonstrated in great abundance; but here they are supposed by Sappey to be derived from the organs to which these membranes are adherent. Their existence in the parietal portion of the membranes is doubtful; and if they exist here at all, their number is not great. Their existence in the synovial membranes is doubtful.

Lymphatics have been demonstrated as taking their origin in the voluntary muscles, the diaphragm, the heart, and the non-striated muscular coats of the hollow viscera, though their investigation in these situations is exceedingly difficult.

Lymphatics are found coming from the lungs in immense numbers. These arise in the walls of the air-cells, and surround each pulmonary lobule with a close plexus. The deep vessels follow the course of the bronchial tubes, passing through the bronchial glands and the glands at the bifurcation of the trachea, to empty into the thoracic duct and the great lymphatic duct of the right side.

In the glandular system, including the ductless glands, and in the ovaries, the lymphatic vessels are, as a rule, more abundant than in any other parts of the body. They are especially numerous in the testicle, the ovary, the liver, and the kidney.

In the substance of the brain and spinal cord, Robin has lately demonstrated a curious system of vessels which entirely surround the capillary blood-vessels, and are connected with the lymphatic trunks or reservoirs described by Fohmann under the pia mater. The capillary blood-vessels thus float in a fluid contained in these cylindrical sheaths, which

[1] SAPPEY, *op. cit.*, tome i., p. 595.

exceed them in diameter by from $\frac{1}{1200}$ to $\frac{1}{400}$ of an inch These investing vessels follow the blood-vessels in their ramifications, and contain a clear fluid, with bodies resembling the lymph-corpuscles. When Robin first described these vessels minutely, he did not state definitely their physiological relations;[1] but he has just published a memoir in which he describes them as true lymphatic vessels, analogous to the lymphatics which partly surround the small blood-vessels in fishes, reptiles, and batrachians.[2] In these animals, the lymphatics in many parts nearly surround the blood vessels, to the walls of which the edges of their proper coat are adherent; and that portion of the wall of the blood-vessel which is thus enclosed forms at the same time the wall of the lymphatic.[3] This disposition of the lymphatics in the brain and spinal cord would allow of free interchange by endosmosis and exosmosis of the liquid portions of the blood and the lymph.

The following are the principal situations, in addition to those already mentioned, in which lymphatic vessels have never been satisfactorily demonstrated, and in which their existence, even, is doubtful: the walls of the blood-vessels; the osseous system; tendons, ligaments, and the general fibrous system. It is almost unnecessary to add that they are not found in the teeth, hair, nails, epidermis, and the epithelial structures.

The lymphatic vessels from the superficial and deep portions of the head and face on the right side, and those from

[1] ROBIN, *Recherches sur quelques Particularités de la Structure des Capillaires de l'Encéphale.—Journal de la Physiologie*, Paris, 1859, tome ii., p. 543 *et seq.*

[2] ROBIN, *Mémoire sur l'Anatomie des Lymphatiques des Torpilles.—Journal de l'Anatomie et de Physiologie*, Paris, 1867, tome iv., p. 3 *et seq.*

[3] The essential anatomical characters of the canals surrounding the blood-vessels in the nervous centres were described by His, in 1865, probably without a knowledge of the previous observations of Robin. (HIS, *On the Existence of a Perivascular Canal-System in the Central Organs of the Nervous System, and upon its relations to the Lymphatic System.—British and Foreign Medico-Chirurgical Review*, January, 1867, p. 237.)

the superficial and deep portions of the right arm, the right half of the chest, and the mammary gland, with a few vessels from the lungs, pass into the great lymphatic duct (ductus lymphaticus dexter), which empties into the venous system at the junction of the right subclavian with the internal jugular. This vessel is about an inch in length and from one-twelfth to one-eighth of an inch in diameter. It is provided with a pair of semilunar valves at its opening into the veins, which effectually prevent the ingress of blood.

The vessels from the inferior extremities, and those from the lower portions of the trunk, the pelvic viscera, and the abdominal organs, generally pass into the thoracic duct. In their course, all of the lymphatics pass through the small, flattened, oval bodies, called the lymphatic glands, which are so abundant in the groin, the axilla, the pelvis, and some other parts. From two to six vessels, called the vasa afferentia, enter these bodies, having first broken up into a number of smaller vessels just before they pass in. They pass out by a number of small vessels which unite to form one, two, or three trunks, generally of larger size than the vasa afferentia. The vessels which thus emerge from the glands are called vasa efferentia.

The lymphatics of the small intestine, called lacteals, pass from the intestine between the folds of the mesentery to empty, sometimes by one, and sometimes by four or five trunks, into the receptaculum chyli. In their course, the lacteals pass through several sets of lymphatic glands, which are here called mesenteric glands.

The thoracic duct, into which the great majority of the lymphatic vessels empty, is a vessel with exceedingly delicate walls, and about the size of a goose-quill. It commences by a dilatation more or less marked, called the receptaculum chyli. This is situated upon the second lumbar vertebra. The canal passes upward in the median line for the inferior half of its length. It then inclines to the left side, forms a semicircular curve something like the arch of the aorta, and empties at

the junction of the left subclavian with the internal jugular vein. It diminishes in size from the receptaculum to its middle portion, and becomes larger again near its termination. It occasionally bifurcates near the middle of the thorax, but the branches become reunited a short distance above. At its opening into the venous system, there is generally a valvular fold, but, according to Sappey, this is not constant.[1] There is always, however, a pair of semilunar valves in the duct, from three-quarters of an inch to an inch from its termination, which effectually prevent the entrance of blood from the venous system.

It is now generally admitted that the lymphatic and lacteal vessels have no connection with the blood-vessels, except by the two openings by which they discharge their contents into the venous system. The foregoing sketch of the descriptive anatomy of what has been called the absorbent system of vessels shows that they may collect fluids, not only from the intestinal canal during digestion, but from nearly every tissue and organ in the body; and that these fluids are received into the venous circulation.

Structure of the Lacteal and Lymphatic Vessels.—The lymphatic vessels, even those of largest size, are remarkable for the delicacy and transparency of their walls. This is well illustrated in the case of the lacteals, which are hardly visible in the transparent mesentery, unless filled with opaque chyle.

From the difficulty in studying the lymphatics at their origin, except by means of injections, or reagents which stain the vessels, investigations into the structure of the smallest vessels have been very few and not very satisfactory. It is supposed, however, that the vessels here consist of a single amorphous coat, resembling, in this regard, the capillary blood-vessels. Dr. Belaieff describes in the capillary lymphatics of the penis, a lining of epithelial cells arranged in a single layer. These cells are oval, polygonal, fusiform or

[1] SAPPEY, *op. cit.*, tome i., p. 621.

dentated, with their long diameter in the direction of the axis of the vessels.[1] The vessels themselves are completely closed; and the openings which were described by the older anatomists were either accidental or imaginary.

In all but the capillary vessels, although the walls are excessively thin, three distinct coats can be distinguished. The internal coat consists of a membrane lined with oblong epithelial cells. These cells, however, do not form a continuous sheet, as in the capillaries. According to some anatomists, the membrane is composed of reticulated longitudinal fibres; but Sappey states that he has never been able to distinguish any appearance of this kind.[2] This coat is somewhat elastic, though it readily gives way when the vessels are forcibly distended. The middle coat is composed of longitudinal fibres of the white fibrous tissue, with delicate elastic fibres and unstriped muscular fibres arranged transversely. The external coat is composed of the same structures as the middle coat; but the fibres are arranged, for the most part, longitudinally. In this coat, the muscular fibres do not form a continuous sheet, but are collected into separate fasciculi, which have a direction either longitudinal or oblique. The fibres of connective tissue are very abundant, and loosely unite the vessels to the surrounding parts. The internal and the middle coat are closely adherent to each other; but the external coat may readily be separated from the others. Blood-vessels have been found in the walls of the lymphatics, but as yet, the presence of nerves has not been demonstrated.

The walls of the lymphatic vessels are very closely adherent to the surrounding tissues; so closely, indeed, that even a small portion of a vessel is detached with great difficulty, and the vessels, even those of large size, cannot be followed out and isolated for any considerable distance.

[1] *Op. cit.—Journal de l'Anatomie et de la Physiologie*, Paris, 1866, tome iii., p. 469.

[2] *Op. cit.*, tome i., p. 625.

In all the lymphatic vessels, beginning a short distance from their plexus of origin, are found numerous semilunar valves, generally arranged in pairs, with their concavities looking toward the larger trunks. These folds are formed of the two inner coats; but the fold formed of the lining membrane is by far the wider, so that the free edges of the valves are considerably thinner than that portion which is attached directly to the vessel. In some of the vessels, at the point where one lymphatic communicates with another, there is a valve formed of two folds, one of which is much wider than the other; but in the valves situated in the course of the vessels, the curtains are of equal size. The valves are very numerous in all of the lymphatics; but they are most abundant in the superficial vessels. Sappey counted from sixty to eighty in the vessels of the arm, from the fingers to the axillary glands, and from eighty to one hundred in the long vessels of the lower extremities.[1] The distance between the valves is from one-twelfth to one-eighth of an inch, near the origin of the vessels, and from one-quarter to one-third of an inch, in their course. In the lymphatics situated between the muscles, the valves are less numerous. They are always relatively few in the vessels of the head and neck and in all that have a direction from above downward. Though there are a number of valves in the thoracic duct, they are not so numerous here as in the smaller vessels.

In their anatomy and general properties, the lymphatics bear a close resemblance to the veins. Though much thinner and more transparent, their coats have nearly the same arrangement. The arrangement of valves is entirely the same; and in both systems, the folds prevent the reflux of fluids when the vessels are subjected to pressure. A number of forces (which will be considered hereafter) combine to produce the flow of lymph and chyle in the absorbent system. Among these is intermittent pressure from surrounding parts, which

[1] *Op. cit.*, tome i., p. 618.

could only operate favorably in vessels provided with numerous valves.

We have already referred to the great elasticity of the lymphatics. It is now pretty generally admitted that the larger vessels and those of medium size are also endowed with contractility, though the action of their muscular fibres, like that of all fibres of the involuntary or non-striated variety, is slow and gradual. Todd and Bowman have demonstrated this property by mechanically irritating the thoracic duct in an animal recently killed, but they observed that the contraction was very slow.[1] Milne-Edwards, quoting from a manuscript presented by Colin to the Academy of Sciences, in 1858, states that this observer noted alternate filling and emptying of some of the lacteal vessels in the mesentery of the ox; portions of the vessels becoming alternately enlarged in the form of pouches, and contracted so that they almost disappeared.[2] There can be no doubt that the lymphatic vessels possess a certain degree of contractility which is fully as marked, perhaps, as in the venous system.

Lymphatic Glands.—In the course of the lymphatic vessels, are found numerous small lenticular bodies, called lymphatic glands. The number of these glands is very great, though it is estimated with difficulty, from the fact that many of them are very small and are consequently liable to escape observation. It may be stated as an approximation that there are from six to seven hundred lymphatic glands in the body. Their size and form is also very variable within the limits of health. They are generally flattened and lenticular, some as large as a bean, and others as small as a small pea, or even a pin's head. They are arranged in two sets: one superficial, corresponding with the superficial lymphatic vessels, and a deep set, corresponding

[1] TODD AND BOWMAN, *Physiological Anatomy and Physiology of Man*, Philadelphia, 1857, p. 615.

[2] MILNE-EDWARDS, *Leçons sur la Physiologie*, Paris, 1859, tome iv., p. 511.

with the deep vessels. The superficial glands are most numerous in the folds at the flexures of the great joints, and about the great vessels of the head and neck. The deep-seated glands are most numerous around the vessels coming from the great glandular viscera. A distinct set of large glands is found connected with the lymphatic vessels between the folds of the mesentry. These are known as the mesentric glands. All of the lymphatic vessels pass through glands before they arrive at the great lymphatic trunks, and most of them pass through several glands in their course.

There is some difference of opinion among anatomists concerning the intimate structure of the lymphatic glands. Some regard them as composed simply of a plexus of lymphatic vessels, held together by a delicate stroma of fibrous tissue; while others deny that there is any direct communication between the afferent and the efferent vessels, assuming that the vessels which penetrate the glands break up into small branches which open into a parenchyma, which is filled with closed follicles, and that the fluids are collected from the glands by a second set of capillaries connected with the efferent lymphatics. According to the latter view, the mesenteric glands are little more than collections of follicles like the solitary glands of the intestines, held together by a delicate fibrous structure. This difference of opinion seems to be due to the different methods which have been employed in studying the structure of the glands. Taking, for example, the results arrived at by two prominent investigators, Sappey, who has studied these organs with great success by injections, seems to have clearly demonstrated a lymphatic plexus in their interior; while Kölliker, whose investigations have been confined chiefly to examinations of the organs in a recent state, has not been able to follow out the lymphatic vessels, but has accurately described the contents of the alveoli, or what are regarded by others as closed follicles. In attempting to represent what has been actually demonstrated concerning the structure of these bodies,

we shall first take up the appearances which are observed in the fresh structures, and afterward those points which have been demonstrated by minute injections.

The perfect healthy glands are of a grayish-white or reddish color, of about the consistence of the liver, presenting a hilum where the larger blood-vessels enter and the efferent vessels emerge, and covered, except at the hilum, with rather a delicate membrane, composed of inelastic, with a few elastic fibres. Their exterior is somewhat tuberculated, from the projections of the follicles just beneath the investing membrane. The interior of the glands is soft and pulpy. It presents a coarsely granular cortical substance, of a reddish-white or gray color, which is from one-sixth to one-fourth of an inch in thickness in the largest glands. The medullary portion, which comes to the surface at the hilum, is lighter colored and coarser than the cortical substance. Throughout the gland are found delicate fasciculi of fibrous tissue connected with the investing membrane, which serve as a fibrous skeleton for the gland, and divide its substance into little alveoli. The structure is far more delicate in the cortical than in the medullary portion. Leydig compares this tissue to that of a sponge, and says that "the connective tissue of the cortical region corresponds to a very fine sponge, and that of the medullary region to a coarse sponge."[1]

Within the alveoli, are irregularly oval, closed follicles, about $\frac{1}{250}$ of an inch in diameter,[2] filled with a fluid and with cells like those contained in the solitary glands of the intestines and the patches of Peyer. These follicles do not seem to occupy the medullary portion of the glands, which, according to Kölliker, is composed chiefly of a net-work of lymphatic capillaries, mixed with rather coarse bands of fibrous tissue.[3] The follicular structures in the lymphatic

[1] LEYDIG, *Traité d'Histologie de l'Homme et des Animaux*, Paris, 1866, p. 457.

[2] ROBIN, *Dictionnaire de Nysten*, Paris, 1865, article *Lymphatique*.

[3] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 507.

glands resemble the closed follicles in the mucous membrane of the intestinal canal and the Malpighian bodies of the spleen.

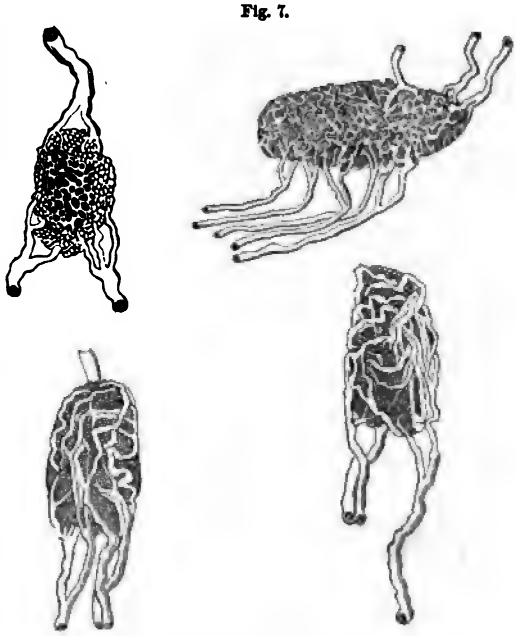
The elaborate researches of Sappey leave scarcely any doubt as to the course and arrangement of the lymphatic vessels in the interior of the lymphatic glands, though the view advanced by him that these bodies consist mainly of lymphatics with a little fibrous tissue cannot be sustained. By pricking a perfectly healthy gland with the delicate point of his apparatus for injecting the lymphatics, he has seen the mercury successively fill the different capillary vessels, and pass into the vasa efferentia.[1] Sappey does not appear, however, to have caused the injection to pass from the afferent to the efferent vessels, entirely through this plexus; and while the fact of the continuity of these vessels through a capillary plexus is extremely probable, it has not, as yet, been positively proven.

As far as has been ascertained, the following is the course of the lymphatic vessels through the glands: From two to six vasa afferentia approach the gland, and when within about a quarter of an inch of it, break up into numerous small branches which penetrate its investing membrane. In the substance of the gland, these vessels are distributed in the capillary plexus just described, and emerge by the vasa efferentia, which are always larger than the afferent vessels, and are from one to three in number. In attempting to pass injections entirely through the glands, the fluid has frequently been observed to pass into the small veins; so that some anatomists have assumed that there is connection in the substance of the glands between the lymphatics and the blood-vessels. It is altogether probable that the passage of fluids into the veins under these circumstances is due to rupture of the vessels; and at all events, the direct connection between them and the lymphatics has never been satisfactorily demonstrated.

[1] SAPPEY, *Traité d'Anatomie Descriptive*, Paris, 1853, tome i., p. 629.

The lymphatic glands are supplied with blood by sometimes one, but generally several small arteries, which penetrate at the hilum. These vessels pass directly to the medullary portion, and there break up into several coarse branches, to be distributed to the cortical substance, where they ramify in an exceedingly delicate capillary net-work, with rather wide meshes, in the closed follicles found in this portion of the gland. This capillary plexus also receives branches from small arterial twigs which penetrate the capsule of the gland at different points. Returning on themselves in the form of loops, the vessels unite to form one or more large veins, which generally emerge at the hilum.

Fig. 7.



Different varieties of lymphatic glands. (SAPPEY, *Traité d'Anatomie Descriptive*, Paris, 1858, tome 1., p. 682.)

Very little is known regarding the distribution of the nerves in the lymphatic glands. A few filaments from the sympathetic system enter with the arteries, but they have never been traced to their final distribution. The entrance of filaments from the cerebro-spinal system has never been demonstrated.

It is evident from the structure of the lymphatic glands,

that they must materially retard the passage of the lymph toward the great trunks; and it is well known in pathology that morbid matters taken up by the absorbents are frequently arrested and retained in the nearest glands.

The function of the lymphatic glands is very obscure. By some they are supposed to have an important office in the elaboration of the corpuscular elements of the lymph and chyle; and it has been observed that the lymph contained in vessels which have passed through no glands is relatively poor in corpuscles, while the large trunks and the efferent vessels contain them in large numbers.[1] This single fact is indefinite enough, as regards the mode of formation of the lymph-corpuscles, but it represents about all that is actually known concerning the function of the lymphatic glands. The mode of development of the leucocytes in this situation will be more fully considered in connection with the lymph and chyle.

In endeavoring to estimate the share which the lacteals and lymphatics have in the function of absorption, it becomes an important question to determine what principles these vessels are capable of taking up, beside the fatty elements of the food; and how far, if at all, they assist the blood-vessels in the absorption of the general products of digestion. It is unnecessary again to recur to the function of the lacteals in the absorption of emulsified fats, for this has already been discussed at sufficient length.[2]

Absorption of Albuminoids by the Lacteals.—Comparative analyses of the lymph and chyle always show in the latter fluid an excess of albumen and fibrin. As we may reasonably suppose that during the intervals of digestion the lacteals carry ordinary lymph, for at this time these vessels are filled with a colorless transparent fluid, having the general physical characters of lymph, it is natural to infer that the

[1] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 513.

[2] See page 426.

excess of albumen and fibrin in the white chyle is due to absorption of albuminoids from the intestinal canal. A number of years ago, experiments were made upon this subject by Prout and Marcet, in which the chyle was collected from the thoracic duct in dogs fed upon different substances. These observers noted marked differences in the composition of the chyle in the animals fed exclusively upon vegetable, and those fed upon animal food; in the latter case, the proportion of albumen being very much greater.[1] The fact that the fluids were taken from the thoracic duct, where the chyle from the intestine is mixed with all the lymph from the lower extremities and the pelvic organs, takes away somewhat from the value of the experiment. This is all the more evident, as in the more recent experiments of Bouchardat and Sandras, it was found that the chyle from the thoracic duct had about the same composition in animals fed with gum, starch, sugar, fibrin, albumen, or gelatine.[2] Bouchardat and Sandras conclude, from these observations, that the lacteals absorb only fats. But the observations of Lane and Rees upon this point, in which the chyle was taken from the lacteals before they emptied into the thoracic duct, are more satisfactory. Mr. Lane collected the chyle from the lacteals of a donkey, seven and a half hours after a full meal of oats and beans, and compared its composition with that of the lymph. The analyses were made by Dr. Rees, who found that the chyle contained about three times as much albumen and fibrin as the lymph.[3] While by far the greater part of the products of digestion of the albuminoids is absorbed by

[1] PROUT, *Phenomena of Sanguification, and on the Blood in general.—Annals of Philosophy*, London, 1819, vol. xiii., p. 25; and MARCET, *Some Experiments on the Chemical Nature of Chyle.—Medico-Chirurgical Transactions*, London, 1819, vol. vi., p. 618.

[2] BOUCHARDAT ET SANDRAS, *Recherches sur la Digestion.—Annuaire de Thérapeutique*, Paris, 1845, p. 259.

[3] LANE, *Lymphatic and Lacteal System.—Cyclopædia of Anatomy and Physiology*, London, 1839–1847, vol. iii., p. 223. These analyses were also published by Rees in the *London Medical Gazette*, January 1, 1841, vol. xxvii., p. 547.

the blood-vessels, there can be no doubt that a small portion is also taken up by the lacteals.

Absorption of Glucose and Salts by the Lacteals.—What has just been stated regarding the absorption of albuminoids applies with equal force to saccharine matters and the inorganic salts. Small quantities of sugar and sometimes lactic acid have been detected in the chyle from the thoracic duct in the herbivora;[1] and the presence of sugar in both the lymph and the chyle has been accurately determined by Colin.[2]

It is true that the products of the digestion of saccharine and amylaceous matters are taken up mainly by the blood-vessels, but a small quantity is also absorbed by the lacteals. In the comparative analyses of the chyle and lymph by Dr. Rees, the proportion of inorganic salts was found to be considerably greater in the chyle.[3] The great excess in the quantity of blood coming from the intestine and the rapidity of its circulation, as compared with the chyle, will explain the more rapid penetration by endosmosis of the soluble products of digestion.

Absorption of Water by the Lacteals.—There can be no doubt that a small portion of the liquids taken as drink finds its way into the circulation by the lacteals, though the greatest part passes directly into the blood-vessels. This has been proven by experiments of a most positive character. Leuret and Lassaigne state that when an animal is fed with an aliment which is very substantial, and is killed during digestion, the thoracic duct contains a very small quantity of chyle; but when the animal has taken liquids with the food, the thoracic duct and the lacteals are very much dis-

[1] Longet, *Traité de Physiologie*, Paris, 1861, tome i., p. 357.

[2] Colin, *De l'Origine du Sucre contenu dans le Chyle.—Journal de la Physiologie*, Paris, 1858, tome i., p. 539 *et seq.*

[3] *Loc. cit.*

tended.[1] In an experiment by Ernest Burdach, a dog was deprived of food and drink for twenty-four hours, after which he was allowed to drink water, and, in addition, half a pound was injected into the stomach. The animal was killed a half an hour after, and the thoracic duct was found engorged with watery lymph, which contained a very small number of lymph-corpuscles.[2]

In discussing the question of absorption by the blood-vessels of the intestinal canal, we alluded to experiments which showed that various poisonous substances introduced into the intestines produced their characteristic effects upon the system with great rapidity when the veins leading from the part were intact, while no such effects followed when the only avenue to the general system was through the lacteals. During the time when the question of exclusive absorption by either the lacteals or the veins was so much agitated, a number of experiments were made by different physiologists to show, on the one hand, that certain coloring matters and salts were absorbed by the lacteals alone, and, on the other, that these were absorbed only by the veins. These experiments have lost much of their interest, now that the question of venous absorption is definitively settled. Without again discussing these observations in detail, it may be stated as the general results of experiments on this subject, that few, if any, of the active poisons were found to be absorbed from the alimentary canal, except by blood-vessels; and when soluble coloring matters, or salts which could be easily recognized, were found in the lacteals or the thoracic duct, after they had been introduced into the intestine, they penetrated in small quantity and very slowly; while it has been repeatedly found that the same substances were taken up by the veins with great rapidity and excreted, in many instances, by the urine.

[1] LECRET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 197.

[2] G. F. BURDACH, *Traité de Physiologie*, Paris, 1841, tome ix., p. 253; addition by Ernest Burdach.

The earlier physiologists, who supposed that all the products of digestion entered the system by the thoracic duct, attached a great deal of importance to experiments showing the effects of shutting off the chyle from the vascular system, by tying or destroying this great canal. A number of very interesting cases of obliteration of the thoracic duct in the human subject has also been reported by Astley Cooper, Andral, and others. In three cases observed by Cooper, the duct was found completely obstructed; and in two, he was able to follow out anastomosing lymphatic branches, which carried the chyle past the obstacle, so that its passage to the venous system was not interrupted. In the remaining case, the obstruction was accidentally discovered in a subject that had been so far dissected as to render it impossible to ascertain whether or not any anastomosing vessels existed.[1] In a case of obliteration of the thoracic duct, reported by Andral, the canal had become an impervious cord for a considerable portion of its extent, but there was a large vessel, like a second thoracic duct, which extended from below the obstruction, opening into the duct a considerable distance above, so that the flow of chyle was not in the least interrupted.[2]

In nearly all the experiments which have been performed upon the lower animals, ligation of the thoracic duct has been followed by death, except where large communicating vessels were found to exist, which would allow of the passage of the chyle into some part of the venous system. Lower tied the duct in dogs, and the animals survived but a few days.[3] In the experiments of Cooper, three dogs, out of four which were operated upon, died from rupture of the

[1] Astley Cooper, *Three Instances of Obstruction of the Thoracic Duct, with some Experiments showing the Effects of tying that Vessel.—Medical Records and Researches selected from the Papers of a Private Medical Association*, London, 1798, p. 86 *et seq.*

[2] Andral, fils, *Recherches pour servir à l'Histoire des Maladies du Système Lymphatique.—Archives Générales de Médecine*, Paris, 1824, tome vi., p. 505.

[3] Lower, *Tractatus de Corde, item de Motu et Colore Sanguinis, et Chyli in eum Transitu.*—Amstelodami, 1669, p. 220 *et seq.*

receptaculum chyli, and in the fourth, which was afterward killed, a vessel was found extending from the duct below the point of ligature to the great lymphatic vein on the right side.[1] The experiments of Dupuytren upon horses were followed by nearly the same results. Some of the animals died after five or six days, and others apparently recovered. In those that died, it was found impossible after death to pass an injection from the lower part of the duct, below the ligature, into the subclavian vein; but in the animals that survived, it was always easy to pass any kind of liquid from the duct into the vein, by numerous communicating vessels located in the posterior and the anterior mediastinum. Magendie, who was present at the dissection of a horse upon which Dupuytren had tied the duct six weeks before, found evident communications between that portion of the duct situated below the point of ligature and both subclavian veins, although the duct itself had been completely obliterated.[2] The experiments of Flandrin seem to indicate that ligation of the thoracic duct is not necessarily fatal, even though the flow of chyle be completely arrested. In one experiment upon a horse that was old and feeble, death took place in three days, while in eleven other experiments, the animals survived, and were killed generally fifteen days after ligation of the duct; but no attempt was made to determine the existence or non-existence of anastomosing branches communicating with the veins in the neck.[3]

The early experiments of Du Verney[4] and others, which

[1] *Loc. cit.*, p. 104 *et seq.* In one of these experiments the duct was simply divided in the neck and was not tied. The animal died on the fifth day.

[2] MAGENDIE, *Mémoire sur les Organes de l'Absorption chez les Mammifères.—Journal de Physiologie*, Paris, 1821, tome i., p. 21.

[3] FLANDRIN, *Suite des Expériences sur l'Absorption des Vaisseaux Lymphatiques dans les Animaux.—Journal de Médecine, Chirurgie, Pharmacie, etc.*, Paris, 1791, tome lxxxvii., p. 226 *et seq.*

[4] *Histoire de l'Académie des Sciences de Paris*, 1675, tome i., p. 197. Du Verney did not tie the thoracic duct, but applied a ligature to "the subclavian vein above the thoracic canal, and the jugular above its insertion."

it is unnecessary to quote in detail, indicate that death must take place after ligation of the thoracic duct, unless there exist some communicating vessel by which the chyle can be discharged into the venous system. We cannot assume, with Lower, that a dog can die of starvation within three days after this operation; but it is an inevitable conclusion, from the experiments cited above, that the cause of death is chiefly mechanical, and is due to distension, and sometimes rupture, of some of the vessels. Cooper found that the receptaculum chyli was ruptured in dogs when the extremity of the duct was exposed soon after eating and simply compressed for a few minutes with the fingers.[1] A permanent loss of the nutritive material which passes up the thoracic duct might produce death from inanition; but usually the fatal result follows too soon to admit of this explanation. Leuret and Lassaigne tied the thoracic duct in a dog, which was treated antiphlogistically after the operation, by M. Watrin, and restored in fifty-eight days in good condition. This animal was afterward killed during digestion, and the abdomen opened. It was ascertained that the duct was single, and the receptaculum and the lacteals contained a small quantity of chyle.[2] Leuret and Lassaigne reasoned, from this single experiment, that there exists a communication between the lacteals and the radicles of the portal vein. They did not, however, demonstrate by injection that there existed no communication between the lower portion of the duct and the veins of the neck.

Absorption from Parts not connected with the Digestive System.—Aside from the entrance of gases into the blood from the pulmonary surface, physiological absorption is almost entirely confined to the mucous membrane of the alimentary canal. It is true that liquids may find their way

[1] ASTLEY COOPER, *op. cit.*, p. 110.

[2] LEURET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 180 *et seq.*

into the circulation through the skin, the lining membrane of the air-passages, the reservoirs, ducts, and parenchyma of glands, the serous and other closed cavities, the areolar tissues, the conjunctiva, the muscular tissue, and, in fact, all parts which are supplied with blood-vessels; but here the absorption of foreign matters is an occasional or an accidental circumstance, and is not connected with the general process of nutrition. It is now well known that all parts of the body, except the epidermis and its appendages, the epithelium, and some other structures which are regularly desquamated, are constantly undergoing change, and the effete matters which result from their decay are taken up by what is called interstitial absorption, and carried by the blood to the proper organs, to be excreted. It would seem probable that the vessels of these parts would also be capable of taking up soluble foreign substances when presented to them; and this is, indeed, the fact with regard to all parts in which the nutritive processes are even moderately active, or where the structures covering the vascular parts are permeable.

Absorption from the Skin.—It is now generally admitted that absorption can take place from the general surface, though at one time this was a question much discussed by physiologists and practical physicians. The proofs, however, of the entrance of certain medicinal preparations from the surface of the body are now entirely conclusive; and the constitutional effects of medicines administered in this way are frequently as marked as when they are taken into the alimentary canal. But the question which is of most interest to us as physiologists concerns the normal functions of the skin as an absorbing surface.

Looking at this subject purely from a physiological point of view, absorption from the skin, under ordinary conditions, must be exceedingly slight, if, indeed, it take place at all. There are a few observations by the older physiologists

which would at first seem to show that a certain amount of water is taken up by the skin when the atmosphere is unusually moist. In all of these, however, the conclusion is drawn from the circumstance that the weight is occasionally somewhat increased under these conditions; but no account is taken of the fact, that when the surrounding atmosphere is moist, the amount of the exhalations is greatly decreased. The lungs, also, present an immense absorbing surface, which is not at all considered. Experiments on this point are not sufficiently definite to warrant any positive conclusions; but it is evident that if any thing enters in this way, the quantity must be excessively minute.

The experiments upon the entrance of water and soluble substances through the skin, when the body has been immersed for a long time in a bath, are somewhat contradictory. Most experimenters have noted an increase in the weight, which they attribute to absorption of water, but others profess to have observed a slight diminution in the weight of the body.

In some experiments on this subject, by Madden, in which all necessary precautions were adopted, the air being respired through a tube passed out of the window of the room, so that no unusual absorption of moisture could take place by the lungs, the results were very conclusive.[1] In experiments of this kind there are many modifying influences to be guarded against. For example, it has been found to be important to regulate carefully the temperature of the bath; for when it exceeds that of the body, there may be a loss of weight by cutaneous transpiration. It is stated by Longet[2] that when the temperature of the water is lower than that of the body, there is a gain in weight; but that the cutaneous exhalation

[1] MADDEN, *An Experimental Inquiry into the Physiology of Cutaneous Absorption*, etc., Edinburgh, 1838, p. 59 *et seq.*

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 296. In the work of Longet will be found a very full account of the various experiments in favor of, and opposed to, cutaneous absorption.

and absorption are balanced when the temperature of the bath and the body are the same. There is another source of complication in these observations, which has been brought forward very strongly by a recent French writer, M. Delore. This observer has carefully noted the increase in weight of the hair, nails, and epidermis, after immersion for half an hour in distilled water, and has always found it to be very considerable. He assumes that this is more than sufficient to account for the increase in the weight of the entire body after immersion in water for half an hour, which amounts to about seven hundred grains.[1]

There are, nevertheless, facts which render it certain that water can be absorbed by the skin. In an elaborate series of experiments by Collard de Martigny, it was proven conclusively that water could be absorbed in small quantity by the skin of the palm of the hand. In one experiment, a small bell-glass filled with water was applied hermetically to the palm. This was connected with a tube bent in the form of a siphon, also filled with water, the long branch of which was placed in a vessel of mercury. After the apparatus had been applied for an hour and three-quarters, the mercury was found sensibly elevated in the tube, showing that a certain quantity of the water had disappeared.[2] Recently a very extended series of observations upon the absorption of water and soluble substances has been made by Dr. Willemin, in which it is conclusively proven that water is absorbed in a bath, and that various medicinal substances may be taken up by the skin in this way, and can be detected afterward in the urine. In a large number of experiments, he found that the weight of the body, after remaining in a tepid bath for from thirty to forty-five minutes, was generally stationary; but

[1] Delore, *De l'Absorption des Médicaments par la Peau saine.—Journal de la Physiologie*, Paris, 1863, tome vi., p. 274.

[2] Collard de Martigny, *Observations et Expériences sur l'Absorption Cutanée de l'Eau, du Lait, et du Bouillon.—Archives Générales de Médecine*, Paris, 1821, tome xi., p. 83.

that sometimes there was a very slight diminution in weight and sometimes a very slight increase. By comparative observations, however, he found that the diminution of weight in the bath was always less than the amount lost by the same subject in the air. Dr. Willemin employed a very delicate apparatus for weighing, and his observations were apparently conducted with great care. He also confirmed the statement of W. F. Edwards and others, that transpiration from the general surface goes on in a bath. This he showed by differences in the composition of the bath before and after immersion of the body. These observations do much to reconcile the contradictory experiments of others, in some of which a diminution in weight was observed, while in some an increase was noted.[1] In studying this subject, it must always be remembered that there is a constant loss of weight by evaporation from the general surface and from the lungs; a fact which was not taken into account by some of the earlier experimenters.

It has been frequently remarked that the sensation of thirst is always least pressing in a moist atmosphere, and that it may be appeased to a certain extent by baths. It is true that, in a moist atmosphere, the cutaneous exhalations are diminished, and this might account for the maintenance of the normal proportion of fluids in the body with a less amount of drink than ordinary; but we could hardly account for an actual alleviation of thirst by immersion of the body in water, unless we assumed that a certain quantity of water had been absorbed. A striking example of relief of thirst in this way is given by Captain Kennedy, in the narrative of his sufferings after shipwreck, when he and his men

[1] WILLEMIN, *Recherches Expérimentales sur l'Absorption par le Tégument externe de l'Eau et des Substances solubles.*—*Archives Générales de Médecine*, Paris, 1863, 6me série, tome ii., pp. 5, 177, 313; and *Nouvelles Recherches sur l'Absorption Cutanée*, Id., 1864, tome iii., p. 513. In the first article, Dr. Willemin gives an admirable historical review of the experiments on cutaneous absorption. The last article contains a great number of original observations, and the conclusions.

were exposed for a long time without water in an open boat. With regard to his sufferings from thirst, he says: "I cannot conclude without making mention of the great advantage I derived from soaking my clothes twice a day in salt water, and putting them on without wringing. . . . . There is one very remarkable circumstance, and worthy of notice, which was, that we daily made the same quantity of urine as if we had drunk moderately of any liquid, which must be owing to a body of water absorbed through the pores of the skin. . . . So very great advantage did we derive from this practice, that the violent drought went off, the parched tongue was cured in a few minutes after bathing and washing our clothes; at the same time we found ourselves as much refreshed as if we had received some actual nourishment."[1]

The mechanism of the introduction of various salts in solution in water and of certain medicinal substances through the skin belongs chiefly to therapeutics. There can be no doubt of the penetration of numerous articles simply placed in contact with the surface; and it is well known that the skin denuded of its epidermis absorbs soluble substances with great rapidity. Though observations on the absorption of salts in medicated baths are somewhat contradictory, there are enough positive experiments on this point to leave no doubt as to the actual penetration of these principles, which are to be recognized, indeed, in the urine. The penetration of most medicinal substances by the skin is very much facilitated by frictions, employing what is known in therapeutics as the iatroleptic method.[2]

Absorption from the Respiratory Surface.—In studying the physiological anatomy of the respiratory apparatus, we

[1] *Narrative of Captain Kennedy's losing his vessel at sea, and his distresses afterward, communicated to his owner.*—*Annual Register*, London, 1769, p. 190.

[2] For a full account of the absorption of medicinal substances by the healthy skin, the reader is referred to the article by Delore, in the *Journal de la Physiologie*, Paris, 1863, tome vi., p. 249 *et seq.*

have seen how admirably the respiratory surface is calculated for the introduction of gaseous principles into the blood.[1] The great rapidity with which the oxygen of the inspired air penetrates through the delicate covering of the pulmonary vessels has already been fully considered under the head of Respiration. Under natural conditions, the gases of the air are the only principles absorbed by the lungs; but examples of the absorption of other gaseous matters are exceedingly common, and this process has been the subject of numerous experiments by physiologists. The fact of the absorption of foreign substances by the lungs, also, has long been definitely settled; but this belongs to pathology or to therapeutics, rather than to physiology.

It is now almost universally conceded that animal and vegetable emanations may be taken into the blood by the lungs and produce certain well-marked pathological conditions. It is supposed that many contagious diseases are propagated in this way, as well as some fevers and other general diseases which are not contagious. With regard to certain poisonous gases and volatile principles, the effects of their absorption by the lungs are even more striking. Carbonic oxide and arseniuretted hydrogen produce death almost instantly, even when inhaled in small quantity. The vapor of pure hydrocyanic acid acts frequently with great promptness through the lungs. Turpentine, iodine, and many medicinal substances may be introduced with great rapidity by inhalation of their vapors; and we well know the serious effects produced by the emanations from lead or mercury in persons who work in these articles. Among the most striking proofs of the absorption of vapors by the lungs are the effects of the inhalation of chloroform and ether. These pass into the blood and manifest their characteristic anæsthetic influences almost immediately. Not only have vapors introduced in this way been recognized in the blood, but many of the principles thus absorbed are excreted by the kidneys, and

[1] See vol. i., Respiration.

may be recognized by their characteristic reactions in the urine.

As would naturally be expected, water and substances in solution, when injected into the respiratory passages, are rapidly absorbed; and poisons administered in this way manifest their peculiar effects with great promptness.[1] Experimenters on this subject have shown the facility with which liquids may be absorbed from the lungs and the air-passages, but it must be remembered that the natural conditions are never such as to admit of this action. The normal function of the lungs is to absorb oxygen, and sometimes a little nitrogen from the air; and the absorption of any thing else by these surfaces is unnatural, and generally deleterious.

Absorption from Closed Cavities, Reservoirs of Glands, etc.—Facts in pathology showing absorption from closed cavities, the areolar tissue, the muscular and nervous tissue, the conjunctiva, and other parts, are sufficiently numerous. In all cases of effusion of serum into the pleural, peritoneal, pericardial, or synovial cavities, in which recovery takes placė, the liquid becomes absorbed. It has been shown by experiment that warm water injected into these cavities is disposed of in the same way. In 1683, Dr. William Musgrave injected water into the thorax of a greyhound, producing at first considerable disturbance, but in a few days the fluid was removed by absorption, and entire recovery took place. On one occasion, a pound and a half of water was injected into one side of the chest and half a pound into the other.[2] Experiments of this nature have been frequently

[1] Numerous experiments, which it is not necessary to discuss in detail, have been performed, showing the prompt absorption of poisons from the respiratory surfaces. Magendie repeatedly showed this with solutions of nux vomica and other poisons, in his public demonstrations (*Phénomènes Physiques de la Vie*, Paris, 1842, tome i., p. 31). It has been found by Magendie and others that this is one of the most rapid ways in which poisons in solution can be introduced into the system.

[2] Musgrave, *Warm Water injected into the Thorax of a Bitch.—Philosophical*

repeated, with the same results. Effusions into the areolar tissue are generally removed by absorption. In cases of penetration of air into the pleura or the general areolar tissue, absorption likewise takes place; showing that gases may be taken up in this way as well as liquids. Effusions of blood beneath the skin or the conjunctiva, or in the muscular or nervous tissue, may become entirely or in part absorbed. It is true that these are pathological conditions, but in the closed cavities, the processes of exhalation and absorption are constantly going on, though not very actively.

Experiments are not wanting to confirm these facts. It is very common to produce dilatation of the pupil by the application of a solution of atropine to the conjunctiva. Magendie made numerous experiments upon the relative rapidity of absorption of poisons from the areolar tissue, the pleura, and some of the other serous cavities.[1] These, however, only confirmed what has been so often observed in pathology and therapeutics. As regards absorption from the areolar tissue, the administration of remedies by the hypodermic method, which is now so common, is a daily proof of the facility with which soluble principles are taken into the blood when introduced beneath the skin.

Under some circumstances, absorption takes place from the reservoirs of the various glands, the watery portions of the secretions being generally taken up, leaving the solid and the organic matters. It is supposed that the bile becomes somewhat inspissated when it has remained for a time in the gall-bladder, even when the natural flow of the secretion is not interrupted. Certainly, when the duct is in any way obstructed, absorption of a portion of the bile takes place, as is proven by coloration of the conjunctiva, and even of the general surface. The serum of the blood, under these conditions, will always be found strongly colored with bile.

Transactions, No. 240, p. 181; reprinted in the Abridgment, London, 1749, fifth edition, vol. iii., p. 78.

[1] MAGENDIE, *Phénomènes Physiques de la Vie*, Paris, 1842, tome i., p. 29 *et seq.*

It is probable that some of the watery portions of the urine are reabsorbed by the mucous membrane of the urinary bladder, when the urine has been long confined in its cavity; though this resorption is ordinarily very slight. A great many cases of discharge of urinary matters by the stomach and intestines, skin, etc., when the urine has been long retained, have been reported by the older physiologists, and were supposed to indicate resorption of these principles from the bladder. The mechanism of the excretion of urinary matters was not understood before the experiments of Prévost and Dumas, who showed that urea will accumulate in the blood after the extirpation of both kidneys in the inferior animals.[1] It is now generally admitted that this takes place when the function of excretion of urine is seriously interfered with, and that an attempt is made by Nature to remove these effete principles from the system by the stomach, intestine, skin, and lungs. It is possible, therefore, that the vicarious discharge of urinary matters in the cases reported, before the true process of excretion by the kidneys was understood, was due to accumulation of the constituents of the urine in the blood, and not their resorption from the urinary passages.

Absorption may take place from the ducts and the parenchyma of glands, though this occurs chiefly when foreign substances have been injected into these parts.

Absorption of Fats and Insoluble Substances.

The general proposition that all substances capable of being absorbed are soluble in water or in the digestive fluids must be modified in the case of the fats. These are never dissolved in any appreciable quantity in digestion, the only change which they undergo being a minute subdivision in the form of a very fine emulsion. In this condition, the fats

[1] PRÉVOST ET DUMAS, *Examen du Sang et de son Action dans les divers Phénomènes de la Vie.—Annales de Chimie et de Physique*, Paris, 1823, tome xxiii., p. 90.

are taken up by the lacteals, and may be absorbed in small quantity by the blood-vessels. Though it is now pretty well understood how endosmotic liquids pass through the walls of the blood-vessels and absorbents, the mechanism of the penetration of fatty particles, which is no less constant, is still somewhat obscure. We cannot at the present day invoke the aid of orifices in the vessels in explanation of this phenomenon; for the opinion of the best anatomists is decidedly against the existence of these orifices in the lacteal capillaries, though some still adhere to the view that they really exist, and it is certain that there are no such openings in the capillary blood-vessels.[1]

There can be no question with regard to the actual penetration of the minute particles of the chyle into the lacteals, and even into the blood-vessels. In birds, indeed, all the fat which is absorbed is taken up by the blood-vessels, the lymphatics of the intestine never containing a milky fluid.[2] Assuming, then, that the walls of these vessels have no orifices through which the fatty particles can pass, it is

[1] It is chiefly with reference to the penetration of fatty particles that the question of the existence or non-existence of orifices in the smallest lacteals is interesting. Cruikshank, who wrote an elaborate memoir on the anatomy of the absorbent system, in the latter part of the last century, not only admits the existence of these openings, but actually estimates their number in each villus. He examined the villi in the intestines of a woman who had died suddenly, and in whom the lacteal system was filled with coagulated chyle. He and Dr. William Hunter examined the villi with the microscope, estimating about fifteen or twenty openings on each villus, in the jejunum.—(CRUIKSHANK, *The Anatomy of the Absorbing Vessels of the Human Body*, second edition, London, 1790, p. 59). Kölliker (*Manual of Human Microscopic Anatomy*, London, 1860, p. 329) describes striæ in the cell-wall, which he remarks may possibly be attributed to extremely fine canals. Beaunis (*Journal de la Physiologie*, Paris, 1863, tome vi., p. 339) quotes and confirms the observations of Recklinghausen (VIRCHOW'S *Archiv*, Berlin, 1862, Bd. xxvi., S. 188), who professes to have demonstrated openings in the lacteals by filling them with a solution of nitrate of silver, when the openings presented the appearance of black points. In none of these observations, is the evidence sufficiently conclusive to warrant the assump tion of the existence of openings in any part of the absorbent system.

[2] BERNARD, *Leçons de Physiologie Expérimentale*, Paris, 1856, p. 317.

evident that under certain circumstances, fatty emulsions must be endosmotic, or, in other words, they are capable of passing through membranes.

It is true that the currents which take place between two miscible liquids of different densities separated by an animal membrane do not usually occur when one of these liquids is a fatty emulsion; and this is explained by the general law that all substances, in order to pass through membranes, must be in solution. It must be remembered, however, that we can but roughly imitate the physiological conditions of any function, in experiments out of the organism. In an endosmometer, we usually have two liquids of different densities separated by the membrane, and the currents are dependent upon very simple physical laws. In the organism, the blood is moving with great rapidity in vessels possessing contractile and elastic coats; the diameter of the vessels is subject to great variations; the liquids which enter the blood-vessels or the lacteals pass through epithelial cells and other structures which are in a condition of continual metamorphosis; the walls of the vessels are thinner than any membrane which we can make use of; and there is a host of conditions which cannot be fulfilled in any apparatus that can be artificially constructed. We may roughly imitate the movement of the circulating fluids, and then it is found that the activity of the endosmotic current is greatly increased.

It has been found, also, that the chemical reaction of the endosmotic liquids has an important influence upon osmotic currents. This latter condition is most interesting with regard to the absorption of fats. While it has been found invariably that neutral emulsions will not pass through membranes and mix with pure water or with neutral fluids, it has been conclusively demonstrated by Matteucci that the passage of fats readily takes place when both of the solutions are alkaline. This observer, having made an emulsion of olive-oil with water containing 4·3 parts per thousand of potash, introduced into it an endosmometer likewise filled with

a feebly alkaline fluid. The membrane used was the urinary bladder of the ox, and the temperature was 80° Fahr. at the beginning of the experiment. In a very short time, the liquid had mounted in the endosmometer more than an inch.[1] In these experiments, the liquids were not more strongly alkaline than the blood or the lymph; and it is fair to infer that in the intestine, where the conditions are as favorable for absorption as possible, the minute fatty particles of the chyle can pass through the coats of the lacteals or the blood-vessels to the lymph and the blood, which fluids are always distinctly alkaline. Though we cannot at present explain precisely how emulsions pass through membranes in which no orifices can be demonstrated, the fact of their penetration can hardly be doubted.

In studying the mechanism of the penetration of fatty particles into the intestinal villi, it has been ascertained that the epithelial cells covering the villi play an important part in this process. It was first ascertained by Goodsir that during the digestion of fat these cells became filled with fatty granules.[2] This fact has been confirmed by Gruby and Delafond,[3] Kölliker,[4] and others. Prof. Dalton, in his work on physiology, figures the appearances of the intestinal

[1] MATTEUCCI, *Leçons sur les Phénomènes Physiques des Corps Vivants*, Paris, 1847, p. 105.

[2] GOODSIR, *On the Structure of the Intestinal Villi in Man and certain of the Mammalia, with some Observations on Digestion, and the Absorption of Chyle.—The Edinburgh New Philosophical Journal*, 1842, vol. xxxiii., p. 167. Goodsir thought that the epithelium of the villi was for the protection of these parts during the intervals of digestion, and that the cells were always desquamated during absorption; but this view is not now entertained.

[3] GRUBY ET DELAFOND, *Résultats des Recherches faites sur l'Anatomie et les Fonctions des Villosités Intestinales, l'Absorption, la Préparation et la Composition organique du Chyle dans les Animaux.—Comptes Rendus*, Paris, 1843, tome xvi., p. 1194. These authors pointed out the differences between the epithelial cells during fasting and during digestion; but they made several errors in their observations, and described openings and ciliæ on the free ends of the epithelium.

[4] KÖLLIKER, *Manual of Human Microscopic Anatomy*, London, 1860, p. 329.

epithelium during the digestion of fat, contrasted with the epithelium observed during the intervals of digestion; showing the cells, during absorption, filled with fatty granules.[1] The hypothesis of Brücke, that the free ends of these cells have no membrane, and that the fat enters to be passed out at openings in the pointed ends, cannot be sustained; for Kölliker has demonstrated that the entire layer of epithelium covering the villi is itself covered by a continuous membrane.[2]

A more accurate knowledge of cell-action might enable us to explain the mechanism of the passage of fat through these structures in the intestine. In the general process of nutrition, fatty granules are frequently deposited in various tissues, cells, etc., by virtue of an inherent property common to all living tissues, which enables them to select, as it were, certain principles from the nutritive fluid. It is as difficult to explain how fatty particles pass out through the walls of the capillary blood-vessels and penetrate cells and other structures, as it is to understand how the particles of chyle penetrate the cells of the intestinal villi and enter the lacteals and blood-vessels. The only purely physical facts which throw any light upon this phenomenon are those of the passage of emulsions through membranes moistened with alkaline fluids. Excessively fine emulsions actually penetrate the intestinal vessels and the structures which cover them; and the fluids contained in these vessels are always distinctly alkaline. How far the epithelial cells covering the villi are concerned in this process is a question which cannot at present be satisfactorily answered.

It is true, as a general law, that insoluble substances, with the exception of the fats, are never regularly absorbed, no matter how finely they may be divided. The apparent exceptions to this are, mercury in a state of minute subdivision like an emulsion, and carbonaceous particles. In the

[1] DALTON, *Treatise on Human Physiology*, Philadelphia, 1864, p. 172.

[2] KÖLLIKER, *loc. cit.*

case of mercury, it is well known that minute particles in the form of unguents may be introduced into the system by prolonged frictions; but this cannot be regarded as an instance of physiological absorption. We have already considered the subject of the passage of small carbonaceous particles through the pulmonary membrane, and have seen that their penetration is purely mechanical.[1] The same thing may possibly occur when fine sharp particles of carbon are introduced into the alimentary canal; but the experiments of Mialhe with pulverized charcoal,[2] and particularly those those of Bérard, Robin, and Bernard with lamp-black introduced into the intestinal canal of animals, showed that though the intestinal mucous membrane became of a deep black, this could easily be removed by a stream of water, and no carbonaceous particles could be discovered in the mesenteric veins, the lacteals, or the mesenteric glands.[3] When the carbon is used in the form of lamp-black, the particles are very minute and rounded, and do not present the sharp points and edges which sometimes enable the grains of pulverized charcoal to penetrate the vessels mechanically.

Variations and Modifications of Absorption.

Very little is known concerning the variations in lacteal or lymphatic absorption; but in absorption by blood-vessels, important modifications occur, due, on the one hand, to different conditions of the fluids to be absorbed, and on the other, to differences in the constitution of the blood and in the conditions of the vessels.

The different conditions of the fluids to be absorbed apparently do not always have the same influence in physiological absorption as in endosmotic experiments made out of the body. Saccharine solutions of different densities con-

[1] Vol. i., Respiration, p. 364.

[2] MIALHE, *Chimie appliquée à la Physiologie*, Paris, 1856, p. 197.

[3] BÉRARD, *Cours de Physiologie*, Paris, 1849, tome ii., p. 729.

fined in distinct portions of the intestinal canal of a living animal do not present any marked variations in the rapidity of their absorption, and they are taken up by the blood, even when their density is greater than that of the blood-plasma. Solutions of nitrate of potash and sulphate of soda of greater density than the serum, which would, therefore, attract the endosmotic current in an endosmometer, are readily taken up by the blood-vessels in a living animal.[1] Indeed, nearly all soluble substances, whatever be the density of their solutions, may be taken up by the various absorbing surfaces during life.

The woorara poison and most of the venoms are remarkable exceptions to this rule. In a series of very interesting experiments upon the absorption of woorara, Bernard has shown that this curious poison, which is absorbed so readily from wounds or when introduced under the skin, generally produces no effect when introduced into the stomach, the small intestine, or the urinary bladder. This result, however, is not invariable, for poisonous effects are produced when the agent is introduced into the stomach of a fasting animal.[2] This peculiarity in the absorption of many of the animal poisons has long been observed; and it is well known that flesh of animals poisoned with woorara can be eaten with impunity. It is curious, however, to see an animal carrying in the stomach without danger a fluid which would produce death if introduced under the skin; and the explanation of this is not readily apparent. The poison is not neutralized by the digestive fluids, for woorara digested for a long time in gastric juice, or taken from the stomach of a dog, is found to possess all its toxic properties, as we have frequently shown (repeating the experiment of Bernard) by poisoning a pigeon with woorara drawn by a fistula from the stomach of a living dog. If we recognize the

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 921.

[2] BERNARD, *Leçons sur les Effets des Substances Toxiques et Médicamenteuses*, Paris, 1835, p. 282 *et seq.*

absorption of this poison simply by its effects upon the system, it must be assumed that, during digestion, it cannot be absorbed by the mucous membrane of the stomach and small intestine, notwithstanding that it is exceedingly soluble.

It has also been shown by Ségalas, that liquids which immediately disorganize the tissues, such as concentrated nitric or sulphuric acid, cannot be absorbed.[1] Another important peculiarity in absorption has been demonstrated by Mialhe, who has shown that solutions which readily coagulate the albumen of the circulating fluids are absorbed very slowly.[2] This is explained on supposition that there is a coagulation of the albuminous fluids with which the absorbing membrane is permeated, which interferes with the passage of liquids. These substances are nevertheless taken up by the blood-vessels, though rather slowly.

The modifications which are due simply to the physical conditions of liquids to be absorbed are chiefly manifested out of the body, and will be considered in connection with the subject of endosmosis.

Influence of the Condition of the Blood and the Vessels on Absorption.—After loss of blood or deterioration of the nutritive fluid from prolonged abstinence, absorption generally takes place with great activity. This is well known, both as regards the entrance of water and alimentary substances and the absorption of medicines. It was at one time quite a common practice to bleed before administering certain remedies, in order to produce their more speedy action upon the system. The increase in the activity of the absorption of poisons by bleeding was strikingly illustrated by Magendie in some of his earliest experiments. He found that when an animal had been bled copiously, the effects of poisons, which were ordinarily manifested after two minutes, appeared with-

[1] SÉGALAS, *Note sur quelques Points de Physiologie.—Journal de Physiologie*, Paris, 1857, tome iv., p. 287.

[2] MIALHE, *Chimie appliquée à la Physiologie*, Paris, 1856, p. 200.

in thirty seconds.[1] In the same series of experiments, the effects of excessive repletion of the vessels were demonstrated. After injecting about a quart of water into the veins of a dog of medium size, absorption was found to be considerably retarded; and in another experiment, in which more than two quarts of water were thus introduced (as much as could be injected without producing death) the absorption of poisons seemed to be arrested; and after having waited half an hour for the phenomena which were generally developed in two minutes, a large opening was made in the jugular vein, and as the vessels became relieved, the toxic effects were manifested.[2]

The rapidity of the circulation has an important influence upon absorption. We have already shown, in treating of the action of the blood-vessels on absorption, that this process may be impeded or even arrested by the ligation of important vessels. It has been evident, also, that absorption is generally active in proportion to the vascularity of different parts. During the process of intestinal absorption, the increase in the activity of the circulation in the mucous membrane is very marked, and undoubtedly has its influence upon the rapidity with which the products of digestion are taken up.

Influence of the Nervous System on Absorption.—Experiments upon the influence of the nervous system on absorption are still very imperfect. It is certain that this process, especially in the stomach, is subject to variations, which can hardly be dependent upon any thing but nervous action. Water and other liquids, which usually are readily absorbed from the stomach, are sometimes retained for a time, and are afterward rejected in nearly the condition in which they were taken. It is probable, however, that the most important influences thus exerted by the nervous system are effected

[1] MAGENDIE, *Mémoire sur le Méchanisme de l'Absorption chez les Animaux à Sang rouge et chaud.—Journal de Physiologie*, Paris, 1821, tome i., p. 5.

[2] MAGENDIE, *loc. cit.*

through the circulation. The recent experiments of Bernard and others upon the sympathetic system of nerves and its connection with the muscular coats of the small arteries, by the action of which the supply of blood in different parts is regulated, point out a line of experimentation which would probably throw much light upon some of the important variations in absorption. When it is remembered that the small arteries may become so contracted under the influence of the sympathetic system, that their calibre is almost obliterated, of course retarding to a corresponding degree the capillary and venous circulation in the parts, and, again, that through the sympathetic nerves the same vessels may be so dilated as to admit to a particular part three or four times as much blood as it ordinarily receives, it becomes apparent that absorption may be profoundly affected through this system of nerves. Unfortunately, there are as yet no definite experiments upon these points. In the observations upon absorption after division of certain nerves by Brodie, Brachet, Longet, and others, attention was always directed particularly to the cerebro-spinal system, and many of the experiments, indeed, were made before much was known concerning the functions of the sympathetic.

As far as the influence of the cerebro-spinal system is concerned, it has been ascertained that while section of some of the nerves distributed to the alimentary canal will slightly retard the absorption of poisonous substances, it is never entirely arrested. Longet found that the operation of strychnine injected into the stomach of a dog in which both pneumogastric nerves had been divided was retarded about five minutes; but that the convulsions, when they occurred, were fully as severe as in an animal which had received an equal dose, without section of the nerves.[1]

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 379.

CHAPTER XVI

IMBIBITION AND ENDOSMOSIS.

General considerations—Imbibition by animal tissues—Mechanism of the passage of liquids through membranes—Observations anterior to those of Dutrochet—Experiments of Dutrochet—Conditions necessary to endosmosis and exosmosis—Influence of membranes upon osmotic currents—Capillary attraction—Imbibition by porous substances—Endosmosis through porous septa—Endosmosis through animal membranes—Endosmosis through liquid septa—Electrical theory of endosmosis—Influence of different liquids upon osmotic currents—Diffusion of liquids—Endosmotic equivalents—Modifications of endosmosis—Modifications due to the extent and the thinness of the permeable membrane—Modifications due to pressure and the movements of liquids—Modifications due to variations in temperature—Modifications induced by electricity—Application of physical laws to the function of absorption—Transudation.

THE ideas of physiologists concerning the mechanism of absorption have become radically changed since the beginning of the present century; and it is now generally admitted that this process takes place chiefly by blood-vessels, and that the absorbents have no orifices endowed with the wonderful elective power which was attributed to them by the older writers. This involves the passage of liquids through the coats of the blood-vessels and lymphatics; a process which has been the subject of numerous experiments, resulting in the development of many important physical laws capable of application to physiological absorption. At the present day, the history of absorption is not complete without a consideration of the laws of imbibition and endosmosis. In accordance with the plan which we have endeavored to follow in the

course of this work, we shall only consider fully those facts in the history of endosmosis which are directly applicable to absorption as it takes place in the living organism; necessarily omitting many points which may be interesting, but which have no direct physiological application. It is important, however, to ascertain precisely how far these physical laws are involved in the passage of liquids through living membranes.

In entering upon the consideration of this subject, it is necessary to appreciate the fact that the walls of the blood-vessels and lymphatics have no pores which are demonstrable; and the supposition that minute orifices exist in these membranes, that cannot be discovered by the highest powers of the microscope, is entirely gratuitous, and has only been advanced for the purpose of affording a purely physical explanation of the passage of liquids.

It is evident that if liquids be capable of passing through the substance of animal membranes, the membrane itself is capable of taking up a certain portion of the liquid by imbibition; and this must be considered as the starting-point in absorption.

Imbibition is, indeed, a property common to all animal structures. One of the most striking characteristics of organic principles is that they may lose water by desiccation and regain it by imbibition. It is also a well-known fact that the tissues do not imbibe all solutions with the same degree of activity. The researches of Liebig have shown that distilled water is the liquid which is always taken up in greatest quantity, and that saline solutions enter the substance of the tissues in an inverse ratio to their density.[1] This is also the fact with regard to mixtures of alcohol and water; imbibition always being in an inverse proportion to the quantity of alcohol present in the liquid. Among the

[1] LIEBIG, *Recherches sur quelques-unes des Causes du Mouvement des Liquides dans l'Organisme Animal.—Annales de Chimie et de Physique*, Paris, 1849, 3me série, tome XXV., p. 367.

other circumstances which have a marked influence upon imbibition, is temperature. It is a familiar fact that dried animal membranes may be more rapidly softened in warm than in cold water; and with regard to the imbibition of liquids by sand, the researches of Matteucci and Cima have shown an immense increase at a moderately elevated temperature.[1] While nearly all the structures of the body will imbibe liquids, after desiccation, the membranes through which the processes of absorption are most active are, as a rule, most easily permeated; and we shall see when we come to study the mechanism of the passage of liquids through these membranes, that the character of the liquid, the temperature, etc., have a great influence upon the activity of this process. For example, all liquids which have a tendency to harden the tissues, such as saline solutions, alcohol, etc., pass through with much less rapidity than pure water. These facts will be found particularly interesting in connection with experiments on the passage of liquids through membranes, in experiments on endosmosis with artificial apparatus.

Mechanism of the Passage of Liquids through Membranes.

The attention of physiologists was first directed to this subject by the researches of Dutrochet, in 1826.[2] Though not by any means the first to observe the phenomena which he described under the name of endosmosis, to Dutrochet is generally ascribed the honor of having first indicated the applications of the laws of endosmosis to the nutrition of plants and animals. Undoubtedly, Dutrochet was the first

[1] MATTEUCCI, *Leçons sur les Phénomènes Physiques des Corps Vivants*, Paris, 1847, p. 23.

[2] The most complete account of these experiments is contained in a collection of memoirs published by Dutrochet, in 1837, entitled *Mémoires pour servir à l'Histoire Anatomique et Physiologique des Végétaux et des Animaux*, tome i., pp. 1-99. A pretty full account is also given by Dutrochet in the *Cyclopædia of Anatomy and Physiology*, article *Endosmosis*, London, 1836-1839, vol. ii., p. 98.

to make experiments upon endosmosis which attracted the attention of scientific men in different parts of the world and were immediately repeated and extended; but the experiments made upon living animals by Lebküchner, in 1819, and by Magendie, in 1820, had already demonstrated most conclusively the passage of liquids through the walls of the blood-vessels; and the explanation offered by these physiologists was fully as definite as that proposed by Dutrochet.

In the experiments of Lebküchner, it was conclusively shown that solutions readily passed through many animal membranes, especially the walls of the blood-vessels. He found that prussiate of potash, placed in contact with the jugular vein of a living rabbit for ten minutes, penetrated into the blood, so that the characteristic reactions with the sulphate of iron were manifested in the serum of the arterial blood and the blood from the jugular upon the opposite side. The same result followed other experiments of the same kind, and experiments with emetic, prussic acid, etc.[1]

In the experiments of Magendie, this observer, refusing to recognize the existence of absorbing openings, either in the lacteals or the venous radicles, showed that when a portion of the jugular vein was plunged into acidulated water, and was so arranged that none of the fluid could enter except through its walls, pure water, when passed in a stream through the vessel, became sensibly acid in from five to six minutes. Another experiment was even more interesting. He exposed in a young dog the jugular vein for its whole length, placed it upon a card, and let fall drop by drop upon its surface a solution of nux vomica, taking care that the poison touched nothing but the card and the vein, and that the course of the blood in the vessel was not interrupted. The effects of the poison were developed in this animal in four

[1] LEBKÜCHNER, *Dissertation inaugurale sur la Perméabilité des Tissus vivans*, Tubingue, 1819. (Extrait.)—*Archives Générales de Médecine*, Paris, 1825, tome vii., p. 439.

minutes. This experiment was repeated upon other animals and upon the carotid artery, with similar results.[1] These observations are referred to in recent French works on physiology, as the first experiments illustrating the operation of imbibition in the process of absorption;[2] but we cannot discover why they do not fully illustrate the passage of liquids through the membranes which form the walls of the blood-vessels. If they had been made after the experiments of Dutrochet, instead of before, they would certainly have been quoted as illustrations of endosmosis.

As regards experiments on the passage of liquids through membranes, out of the body, those made by the Abbé Nollet, in 1748 (probably the first on record), are most striking, when brought in comparison with the illustrative experiments made on endosmosis at the present day.

In the course of a series of observations on the causes of the ebullition of liquids, Nollet filled a vial about five inches long with alcohol, covered it tightly with a moistened bladder, and immersed it in pure water. In five or six hours, he found that the water had passed through the membrane to the alcohol, and the bladder had become convex. It first occurred to him that this might be due to a difference in the temperature of the two liquids; but the same phenomenon was presented when the temperature of the liquids was the same. On filling the vial with water and immersing it in alcohol, the action was reversed, and the membrane became concave. By a series of ingeniously contrived experiments, he also ascertained that water could readily be forced through a membrane, while alcohol passed through in small quantity and only under great pressure.[3]

[1] MAGENDIE, *Mémoire sur le Mécanisme de l'Absorption chez les Animaux à Sang rouge et chaud, lu à l'Académie des Sciences de Paris*, octobre, 1820.—*Journal de Physiologie*, Paris, 1821, tome i., p. 1 *et seq.*

[2] MILNE-EDWARDS, *Leçons sur la Physiologie*, Paris, 1859, tome v., p. 25; and LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 381.

[3] NOLLET, *Recherches sur les Causes du Bouillonnement des Liquides.—Mémoires de l'Académie Royale*, Paris, 1748, p. 101 *et seq.*

From the beginning of the present century, up to 1826, several isolated observations were made on the passage of liquids through membranes. In 1802, Parrot noted the passage of water through the membranes of an egg which had no calcareous covering;[1] in 1816, Porrett noted that the galvanic current was capable of causing water to pass through an animal membrane;[2] and finally, in 1822, Fischer, professor at Breslau, actually constructed an endosmometer, and noted the elevation of the liquid in the tube above the level of the liquid in which the apparatus was placed. The experiments of Fischer were more complete, and illustrated the laws of endosmosis more fully, than is generally supposed. Not only did he construct an endosmometer, closing the lower portion of his apparatus with an animal membrane, and noting the passage of pure water through the membrane to a saline solution, but he described the exosmosis of the saline solution, and observed that the currents continued until both liquids became of equal density. He also noted that the currents were active in proportion to the thinness of the animal membrane used.[3]

To return to the observations of Dutrochet, it is universally acknowledged that he was the first to describe fully and definitely the passage of liquids through animal membranes, out of the body; to show the influence of different liquids used; to measure the force of the different currents; and, finally, to give to these actions the names of endosmosis and exosmosis.[4] He constructed an instrument known as

[1] PARROT, *Phénomène frappant d'Endosmose dans l'Organization animale.—Bulletin Scientifique de l'Académie de St. Petersbourg*, 1840, tome vii., p. 346.

[2] PORRETT, *Curious Galvanic Experiments.—Annals of Philosophy*, London, 1816, vol. viii., p. 74.

[3] FISCHER, *Ueber die Wiederherstellung eines Metal's durch ein anderes und über die Eigenschaft der thierischen Blase Flüssigkeiten durch sich hindurch zu lassen, und sie in einigen Fällen anzuheben.*—GILBERT'S *Annalen der Physik*, Leipzig, 1822, Bd. lxxii., S. 301.

[4] DUTROCHET, *De l'Endosmose.—Mémoires pour servir à l'Histoire Anatomique et Physiologique des Animaux*, Paris, 1837, tome i., p. 1 *et seq.*

Dutrochet was first led to study the phenomena of endosmosis by observing

the endosmometer; which consists simply of a small bell-glass, the lower opening of which is closed by a membrane, the opening above being connected with a long glass tube by which the force with which liquids pass through the membrane can be measured. The bell-glass is generally filled with a liquid capable of attracting a current of water from without, and is immersed in pure water, so that the membrane is completely covered. Under these circumstances, there is a current of water through the membrane, which will cause the liquid to mount in the tube, sometimes to the height of several feet; but at the same time, there is a feebler current from the interior of the apparatus to the water. Dutrochet called the stronger, the endosmotic current, and the feebler, the exosmotic current. This nomenclature, however, is not strictly accurate; for if the position of the liquids be reversed, as was shown in the old experiments of Nollet, the stronger current is exosmotic and the feebler is endosmotic. It must be remembered, therefore, that the name endosmosis is always to be understood as applied to the principal current, while the term exosmosis is applied to the current in the opposite direction. This possible inaccuracy of expression has led to the adoption by Graham and others of the term osmosis, as applied generally to the currents which take place through membranes;[1] but the terms first proposed by Dutrochet are most commonly used.

The phenomena of endosmosis, which, since the publication of the researches of Dutrochet, have been so closely studied by physicists, are chiefly interesting to the physiologist in their application to absorption. While it is perhaps true that all the phenomena of physiological absorption

that little organic vesicles, when immersed in water, discharged a portion of their contents through their investing membranes. This fact he communicated to the Philomathic Society of Paris, in 1809 (*op. cit.*, p. 5), but as we have already seen, essentially the same phenomenon was observed in an egg by Parrot, in 1802.

[1] GRAHAM, *On Osmotic Force.—Philosophical Transactions*, London, 1854, p. 177 *et seq.*; and *Elements of Inorganic Chemistry*, Philadelphia, 1858, p. 746.

cannot as yet be explained upon purely physical principles, it is nevertheless important to ascertain how far physical laws are involved in this process. With this end in view, we shall study the physical phenomena of endosmosis, chiefly with reference to their physiological applications.

It is now definitely ascertained that the following conditions are necessary for the operation of endosmosis and exosmosis:

1. That both liquids be capable of "wetting" the interposed membrane, or, in other words, that the membrane be capable of imbibing both liquids. If but one of the liquids can wet the membrane, the current can take place in only one direction.

2. That the liquids be miscible with each other, and be differently constituted. Though it is found that the currents are most active when the liquids are of different densities, this condition is not indispensable; for currents will take place between solutions of different substances, such as salt, sugar, or albumen, though they may have precisely the same density.

The physiological applications of the laws of endosmosis can now be more fully appreciated, as it is evident that the above conditions are fulfilled whenever absorption takes place; with the single exception of the absorption of fats, which has been specially considered. For example, all substances are dissolved or liquefied before they are absorbed, and in this condition are capable of wetting the walls of the blood-vessels; and all the liquids absorbed are capable of mixing with the plasma of the blood.

What makes this application still more complete is the behavior of albumen in endosmotic experiments. In physiological absorption, there is always an immense predominance of the endosmotic current, and there is very little transudation, or exosmosis, of albumen, the chief nutritive constituent of the blood. On the other hand, there is a constant absorption of albuminose, which is destined to be con-

verted into the albumen of the blood. Mialhe, in comparing the endosmotic properties of albumen and albuminose, has given an explanation of these remarkable phenomena.

Recognizing the fact, which was, indeed, pointed out clearly by Dutrochet, that albumen is capable of inducing a more powerful endosmotic current than almost any other liquid, he has shown that it never itself passes through membranes in the exosmotic current; but that albuminoids, after transformation by digestion into albuminose, or albumen mixed with gastric juice, pass through animal membranes with great facility. The experiments by which these facts are demonstrated are very conclusive, and are of the highest physiological importance. On removing part of the shell of an egg, so as to expose its membranes, and immersing it in pure water, the passage of water into the egg was rendered evident by the projection of the distended membranes; but although the surrounding liquid had become alkaline, and the appropriate tests revealed the presence of some of the inorganic constituents of the egg, the presence of albumen could never be detected.[1] When the contents of the egg were replaced by the serum of the blood, the same result followed. "After six or eight hours of immersion, the serum had yielded to the water in the vessel all its saline elements, chlorides, sulphates, phosphates, which were easily recognized by their peculiar reactions, but not an atom of albumen." [2]

[1] MIALHE, *Chimie appliquée à la Physiologie et à la Thérapeutique*, Paris, 1856, p. 141.

[2] *Loc. cit.*, p. 142.

The above experiment possesses additional interest, as it illustrates a new principle recently announced by Graham, called dialysis. This is dependent simply upon the fact that various membranes and some porous septa, when used in an apparatus like an endosmometer, will allow only "crystalloid" bodies to pass through; while the organic substances, called by Graham "colloids," are retained. For example, if a fluid containing an inorganic substance, such as a salt of arsenic, mixed with organic matter, be placed in the interior of such an apparatus, and

Influence of Membranes upon Osmotic Currents.

The force with which liquids pass through membranes, called endosmotic or osmotic force, is to a great degree dependent upon the influence of the membranes themselves. This influence is always purely physical, in experiments made out of the body; and physiological absorption can be explained, to a certain extent, by the same laws. It must be remembered, however, that the properties of organic structures, which are manifested only in living bodies, are capable of modifying these physical phenomena to a remarkable degree. For example, all living tissues are capable of selecting and appropriating from the nutritive fluids the materials necessary for their regeneration; and the secreting structures of glands also select from the blood certain principles which are used in the formation of their secretions. At the present day these phenomena, and their modifications through the nervous system, cannot be fully explained. This is true, also, of many of the phenomena of absorption and their modifications, which are probably dependent upon the same kind of action. In view of these undoubted facts, the influence of the structures through which liquids pass in physiological absorption may be divided: first, into physical influences, which may be illustrated by endosmotic experiments with organic membranes out of the body; and second, modifications of these phenomena, which are presented only in the living organism.

One of the earliest theories which was offered in explanation of the passage of liquids through membranes, makes it dependent entirely upon the laws of capillary attraction and of the diffusion of liquids; and to appreciate fully the views of those who adopt this purely physical theory, it will

the whole be immersed in pure water, in the course of about twenty-four hours, one-half or three-fourths of the crystalloid matters will be found in the surrounding liquid, entirely separated from the colloid matters. An apparatus of this kind, called a dialyser, has been found very useful in certain inorganic analyses.

be necessary to pass in review the laws which regulate these phenomena. This is all the more necessary, as in most works upon physics, the physiological application of these laws are not fully appreciated; while, on the other hand, physiologists are too apt to neglect physical explanations of the so-called vital phenomena.

Capillary attraction is dependent upon an adhesive force or attraction between certain surfaces and certain liquids. A liquid, in order to be subject to this force, must be capable of wetting the surface to which it is exposed. This is illustrated by the well-known attraction between water and glass. If a drop of water be placed upon a clean glass plate, it becomes flattened and adheres to the surface; and when the plate is inclined, runs to the edge, leaving a wet line, and does not fall to the ground, but adheres to the plate and is sustained against the force of gravity. If the plate be carefully covered with grease, the drop of water will not adhere to the surface, and is more nearly spherical; and when the plate is inclined, it rolls to the edge and falls to the ground. This is explained by the fact that water is not capable of wetting a greased surface. If a globule of mercury be placed upon the glass plate, instead of water, it moves about freely, and falls to the ground, because no attraction exists between it and the surface.

If the experiment be now modified by partly immersing a clean glass plate in a vessel of water, another set of phenomena is presented. At the point where the glass is in contact with the surface of the liquid, a slight elevation of water along the sides of the glass will be observed, which is in opposition to both the force of gravitation and the cohesive molecular attraction between the particles of the liquid. No argument is necessary to show that, within certain limits imposed by the law of gravitation, the ascent of liquids thus attracted by the surfaces of solids will bear a direct ratio to the predominance of the adhesive attraction between the surface and the liquid over the cohesive attraction between the molecules of

the liquid. The elevation of the liquid can therefore be increased by diminishing the amount of liquid and increasing the extent of the attracting surface. This is illustrated by a modification of the last experiment. If the surface of the liquid near the plate of glass be carefully examined, it will be found to present a curve, which extends from the highest point to which the liquid has ascended on the glass to the general level. If we now divide the liquid into imaginary parallel strata of infinite thinness, it is evident that the layer of liquid next the glass is most powerfully attracted and has mounted highest; that the second stratum, being removed from the surface, is less powerfully attracted, and is influenced to a greater degree by the cohesive attraction between the molecules of the liquid; and that, as we recede from the glass surface, the attractive force is progressively diminished and the cohesive force progressively increased, until, when the general level of the liquid is reached, the attractive force is lost. Suppose now that a second plate of glass be placed parallel to the first, the liquid between the two plates will be subjected to double the amount of attraction, and will form a concave surface, the lowest point being equidistant between the two plates. The nearer these two plates are brought together, the smaller will be the quantity of liquid, and the molecular attraction between its particles will necessarily be proportionately diminished. This may be shown by approximating the glasses at one end, and progressively increasing the distance between them to the other. The liquid will then form a curve between the plates, the highest point being where they are most closely approximated.

If tubes be used instead of plates of glass, the foregoing facts are more strikingly illustrated. The nearer the internal surfaces of the tube are brought together, or, in other words, the smaller the calibre of the tube, the greater will be the elevation of liquid in its interior. It is because liquids are observed, in accordance with this law, to mount highest in

tubes of capillary diameter, that this force has been called capillary attraction.

There is no essential difference between the phenomena of imbibition by porous substances and the elevation of liquids in capillary tubes. In both, it is necessary that the liquid should be capable of wetting the surfaces to which it is exposed. The imbibition of water by a sponge is dependent upon capillary attraction. If the liquid thus taken up remain and fill the interstices, no current takes place; but if it be constantly removed by evaporation, or otherwise, a constant flow is produced. It is in this way that an alcohol-lamp is emptied of fluid, which is taken up by the wick and lost by evaporation. This single current is produced by the diffusion of the liquid in the atmosphere in the form of vapor; but if an apparatus be constructed in which the liquid absorbed is gradually diffused in another liquid, the result will be the same. Suppose, for example, that an endosmometer be constructed in which the septum consists of a porous substance, such as unglazed earthenware. Let this apparatus be so filled with a saline solution, and the septum immersed in pure water. The porous septum will then gradually take up the water and bring it in contact with the saline solution; when, in obedience to the law of diffusion of liquids, the water passes in a diffusive current to the saline solution, and a steady current will be established through the septum. As diffusion can only take place between liquids which are miscible with each other, this condition is indispensable to the production of a current. If we now suppose that both liquids are capable of wetting the septum, in such an apparatus as we have described, they will meet in the substance of the septum. Once in contact with each other, whether within or without the septum, the liquids will diffuse; the water flowing toward the saline solution, which in its turn flows toward the water. In this way, two currents are produced. It has been found in experiments of this kind that the two currents are generally unequal, the more power-

ful corresponding to the endosmotic, and the feebler to the exosmotic current. This inequality in the currents is explained by the fact that porous substances imbibe different liquids with different degrees of activity;[1] so that the septum always contains a greater quantity of one of the liquids. It is the liquid thus introduced in greater quantity in which the more powerful current is developed. In this case, also, the difference in the diffusibility of the liquids has an important influence; but these phenomena will be more fully considered when we come to treat of the influence of different liquids upon endosmosis.

Numerous experiments have demonstrated that both the endosmotic and the exosmotic current may be produced by using a porous instead of a membranous septum, though they are always more feeble.[2] The phenomena thus presented are to be explained entirely by the laws of capillary attraction and of the diffusion of liquids. These laws would enter largely into the explanation of the passage of liquids through animal membranes, if it could be demonstrated, or even rendered probable, that these membranes are porous, or are provided with capillary openings. It will be necessary, however, to study this question very carefully,

[1] This fact is strikingly illustrated in some of the experiments of Matteucci on the imbibition of different solutions by tubes filled with fine sand (*Leçons sur les Phénomènes Physiques des Corps Vivants*, Paris, 1847, p. 21).

[2] DUTROCHET, *De l'Endosmose.—Mémoires pour servir à l'Histoire Anatomique et Physiologique des Végétaux et des Animaux*, Paris, 1837, tome i., pp. 21–23.

Dutrochet made a number of experiments with different porous septa. He found it impossible to produce endosmosis through thin sections of sandstone or of imperfectly baked porcelain; but with a septum of potter's clay, one-twenty-fifth of an inch thick, there was a tolerably energetic endosmotic current. The same result followed when the septum was from one-twelfth to one-fifth of an inch thick; but in septa of greater thickness than this, the currents were very feeble. These experiments were repeated by Graham with more satisfactory results. By employing a porous jar, such as is used in Grove's battery, vigorous endosmotic and exosmotic currents were produced.—(*On Osmotic Force.—Philosophical Transactions*, London, 1854, p. 180.)

and examine all the properties of animal membranes, both within and without the living organism.

In the first place, is there any proof that all membranes which will admit the passage of liquids are porous? This is a most important question; and it lies at the foundation of the explanation of the phenomena of endosmosis by the laws of capillary attraction.

In all membranes which possess an anatomical structure discoverable by the microscope, there are undoubtedly interstices between the fibres, cells, etc., of which the tissue is composed; but on the other hand, animal membranes generally have a layer, like the basement-membranes of mucous tissues, which is absolutely homogeneous and structureless. In applying the laws of endosmosis to physiological absorption, it is found that the membranes which are most easily penetrated by fluids are excessively thin and perfectly homogeneous. Take, for example, the walls of the capillary blood-vessels, through which the greatest part of the physiological absorption takes place; this membrane is from $\frac{1}{25000}$ to $\frac{1}{12500}$ of an inch thick, and is entirely amorphous, with the exception of a few oval nuclei imbedded in its substance. The assumption that invisible capillary orifices exist in these thin amorphous membranes is purely hypothetical, and is unwarrantable. The only circumstance which could lead to such a supposition is the fact that these membranes can be penetrated by liquids.

It is manifestly unphilosophical and absurd to offer, as an explanation of endosmosis through structureless membranes, an hypothesis which has its only support in the existence of the phenomenon which it is intended to explain. This mode of reasoning is all the more unsound, as the phenomena of endosmosis are very far from being completely understood; and many important properties of organic structures, which bear directly upon the question under consideration, are ignored. For example, physiological absorption does not always take place in accordance with known physical laws.

It undergoes modifications which can at present only be explained on the supposition that the liquids become, for the time, part of the living organic structures and partake of their peculiar properties; one of them, the property by virtue of which they appropriate both the organic and the inorganic principles necessary to their proper constitution and regeneration, is called by some, vital; a word which simply expresses ignorance of its essential character. It must be understood, however, that this remark does not apply to the general phenomena of endosmosis or absorption, but only to certain of its unexplained modifications.

A most important property of organic tissues, which is ignored by those who explain absorption on the principle of capillary attraction, is that of hygrometricity. All the organic nitrogenized proximate principles are capable of losing their water of composition by desiccation and of regaining it by imbibition. The water which enters into their composition is not necessarily contained in interstices in the tissue, but, in the case of structureless parts especially, is uniformly disseminated, or we may term it diffused, throughout the organic substance, of which it forms a constituent part. This action of certain liquids upon the organic semisolids is something like the diffusion of liquids; the difference being that it is the liquid only which is diffused in the semisolid, the semisolid being incapable of diffusing in the liquid.[1] As it has been found that all liquids are not equally subject to capillary attraction, so animal tissues imbibe different liquids with different degrees of activity;[2] a fact which will account in a measure for the variations in the endosmotic currents with different solutions.

Examples are not wanting of endosmosis by imbibition or diffusion, when it cannot be assumed that there is any

[1] The liquid organic principles, such as albumen and caseine, are capable of diffusing with other liquids, but the cohesion of membranes is too powerful to allow of this reciprocal action.

[2] See page 470.

such thing as porosity in the septum. The following experiment of Lhermite fully illustrates this point. A tube was partly filled with a column of chloroform; and upon this was poured a layer of water, and above it a layer of ether. The ether gradually penetrated the layer of water and passed to the chloroform, mingling with it. After a certain time, all the ether had thus been diffused in the chloroform, and the layer of water retained its original volume.[1] We have repeated this experiment with some slight modifications, using first a layer of sulphuric acid, then a layer of water, and finally a solution of blue litmus in alcohol; and in a very short time the acid penetrated the water and reddened the litmus above. A liquid septum is certainly not porous, in any sense of the word; and the explanation of the phenomenon of endosmosis through liquids depends simply upon the law of diffusion of liquids, the molecules of the liquids being held together so feebly that they will admit the molecules of other liquids with which they are capable of mixing.

With regard to the passage of liquids through different septa, the following seem to be the facts which can be considered as definitely settled:

The cohesive attraction of the constituent particles of insoluble solids is so great, that the entrance of fluids is impossible, unless the substance be porous; and this always involves the law of capillary attraction; but in liquids, the cohesive attraction is so slight as to admit of the penetration and diffusion of certain other liquids.

Homogeneous animal membranes, which are of a semi-solid consistence, are capable of imbibing certain liquids; and any liquid which can pass into such membranes, under proper conditions, will pass through them. The cohesive attraction of the particles of the membrane is not such as to allow them to imbibe an indefinite quantity of any liquid; but it is one of the distinctive properties of organic tissues

[1] LHERMITE, *Recherches sur l'Endosmose.—Comptes Rendus*, Paris, 1854, tome xxxix., p. 1179.

that a limited quantity of liquid can be taken up in this way.

In view of these facts, it is not necessary to assume the existence of infinitely small capillary openings in homogeneous membranes through which osmotic currents can be made to take place, in order to explain the mechanism of these currents. In the case of two liquids capable of diffusing with each other and separated by an animal membrane, the mechanism of the endosmotic and exosmotic currents is very simple. In the first place, the membrane imbibes both the liquids, but one is always taken up in greater quantity than the other. If water and a solution of common salt be employed, the surface of the membrane exposed to the water will imbibe more than the surface exposed to the saline solution; but both liquids will meet in its substance. The first step, therefore, in the production of the currents is imbibition. Once in contact with each other, the liquids diffuse; the water passing to the saline solution, and *vice versa.* This takes place by precisely the same mechanism which has been described in connection with the passage of liquids through porous septa.

In the observations of Porrett,[1] it was observed that the galvanic current was capable of causing water to pass through animal membranes. Carrying out this idea, Dutrochet first supposed that the attractive force which operated in endosmosis was due to electrical action; but this view he subsequently abandoned.[2] This theory was afterward advanced by Draper,[3] who noted the fact that a drop of water placed upon the surface of mercury could be made to spread out into a thin film and wet the mercury, by connecting the globule with the positive pole of a galvanic battery and

[1] PORRETT, *Curious Galvanic Experiments.—Annals of Philosophy*, London, 1816, vol. viii., p. 74.

[2] *Op. cit.*, p. 70.

[3] DRAPER, *On the Mechanical Functions of Areolar Tissues.—American Journal of the Medical Sciences*, August, 1838, p. 308.

the mercury with the negative pole. This experiment simply illustrates the fact that attractive force can be generated by galvanic action. It is well known that endosmosis can be greatly modified by galvanism, but the supposition that capillary attraction is an electric phenomenon is purely hypothetical and is entertained by few physicists. The numerous publications by different experimenters, which immediately followed the publication of the observations of Dutrochet,[1] many of them in this country, did little more than confirm the facts demonstrated by Dutrochet, differing only on theoretical points. A consideration of these, however, belongs more to physics than to physiology.

It was first supposed by Dutrochet that the endosmotic current always took place from the rarer to the denser liquid; and it was found, in using different saline solutions, that within certain limits, the activity of the current was in proportion to the density of the solution in the endosmometer. But this error was soon corrected by more extended experiments, in which endosmotic currents frequently took place from the denser to the rarer liquids, as is the case with water and alcohol, and with alcohol and ether.[2] It is now fully recognized that the osmotic currents are not necessarily dependent upon the different densities of the liquids, but are due chiefly to their different affinities for the intervening membrane.

The osmotic currents may be modified with the same li-

[1] TONGO, *Experiments to prove the Existence of a peculiar Physico-organic Action, inherent in Animal Tissues, called Endosmose and Exosmose.*—*American Journal of the Medical Sciences*, May, 1829, p. 73.

——JACKSON, *On Absorption*, Ibid., Feb., 1830, p. 277.

——MITCHELL, *On the Penetrativeness of Fluids*, Ibid., Nov., 1830, p. 36.

——VALK, *Microscopical Observations on Portions of Animal Tissue, with additional Experiments on Endosmose and Exosmose*, Ibid., Feb., 1831, p. 405.

——DRAPER, *Experiments on Absorption*, Ibid., May, 1836, p. 13. *On the Physical Action of the Capillary Systems.* Ibid., Feb., 1838, p. 289; and, *On some Mechanical Functions of Areolar Tissues*, Ibid., May, 1838, p. 23, and August, 1838, p. 302.

[2] DUTROCHET, *op. cit.*, p. 40.

quids, by using different membranes. This fact was well illustrated in some of the experiments of Matteucci and Cima, in which comparative observations were made upon the currents through the skin of the torpedo, the skin of the frog, and the skin of the eel. The results obtained with these different membranes showed marked and constant variations. The same observers, in using the mucous membrane of the stomach of the lamb, found a marked difference in the endosmotic phenomena when the surface exposed to the water was reversed. In two experiments, with the epithelial surface of the membrane turned toward the interior of the endosmometer, the elevation of the liquid in an hour and a quarter was from forty-four to fifty-six millimeters; but with the membrane reversed, so that the attached surface was turned toward the interior, the elevations during the same period were sixty-six and seventy-two millimeters.[1] This difference is readily explained by the difference in the constitution of the two surfaces of the membrane used.

From these facts it is evident that while the diffusion of liquids as they meet in the substance of a membrane is the actual cause of the osmotic currents, which are continued as the liquids diffuse with each other upon either side of the membrane, the determination of a predominating or endosmotic current, the ordinary conditions being undisturbed, is effected by the greater attractive force which the membrane exerts upon one of the liquids.

Influence of Different Liquids upon Osmotic Currents.

The action of the liquids between which endosmotic currents take place is, as we have seen, most intimately connected with the force by which the liquids enter the membrane, be it capillary attraction or imbibition; but the attractive force exerted by the membrane is never capable, in itself, of producing a current. It is evident, therefore, that

[1] MATTEUCCI, *Leçons sur les Phénomènes Physiques des Corps Vivants*, Paris, 1847, pp. 48, 51.

the properties of the liquids must have an important influence upon osmose, both from differences in the attraction of the membrane for the liquids, and their different degrees of diffusibility. In order to appreciate fully all the physical phenomena of osmose, it will be necessary to study carefully the laws of diffusion of liquids and the diffusibility of different solutions; but it will be sufficient for our present purpose to state a few general propositions, which will be found more or less applicable to physiological absorption.

When two liquids, capable of mixing with each other, are brought together, they diffuse with greater or less rapidity, until the constitution of the mixture becomes uniform.

Different liquids possess widely different degrees of diffusibility; and as a rule, in saline solutions, the rate of diffusion increases in proportion to the strength of the solution, at least when the quantity of salt dissolved does not exceed four or five per cent.[1] It follows from this that the activity of the endosmotic current toward any saline solution will be greatest at the beginning of the experiment, and will progressively diminish as the currents continue and the two liquids assume a more nearly uniform density.

The rate of diffusion of different solutions is generally increased by a moderate elevation of temperature.

Bearing in mind these general laws, and remembering that they are applicable to diffusion as it takes place through animal membranes, we can easily understand how different liquids and solutions, in an endosmometer, will attract with different degrees of intensity any given liquid, such as pure water; and how this attractive force, which is measured by the rapidity and extent of the rise of liquid in the endosmom-

[1] GRAHAM, *Elements of Inorganic Chemistry*, Philadelphia, 1858, p. 743.

The diffusibility of different acid and saline solutions has been very fully investigated by Graham, who has developed many interesting facts showing the influence of different liquids upon osmotic phenomena. For further information on this subject, the reader is referred to the papers published by Graham in the *Philosophical Transactions*, in 1849, 1850, and 1857; and to the chapter on "Diffusion of Liquids," in the *Elements of Inorganic Chemistry*, by the same author.

eter, may be modified by the concentration of the solution, differences in temperature, and other conditions. The influence which the membrane exerts upon the relative intensity of these currents is dependent to a certain extent upon the diffusion which takes place when the two liquids come together in its substance.

As a rule to which there are not very many exceptions, pure water will penetrate animal membranes more readily than any other liquid; and it is consequently from the water to the liquid contained in the endosmometer that the principal current generally takes place. Liquids like alcohol, saline solutions, etc., which have this property, are said to be positively osmotic; while those with which the current takes place in the opposite direction, such as oxalic acid, weak hydrochloric acid, bichloride of platinum, etc., are said to be negatively osmotic. In a series of experiments with different liquids, if the endosmometer be always the same, and all the liquids used be exposed to the action of pure water, in a given time a definite change in the quantity of fluid in the endosmometer will be produced, which will be indicated by a certain amount of elevation or depression in its level.

Endosmotic Equivalents.—The term endosmotic equivalent is often used in comparing the endosmotic power of different solutions. The degrees by which these equivalents are represented are entirely arbitrary, and are intended to represent the force with which various solutions attract pure water. Among those who have experimented upon this subject, Graham has, perhaps, made the greatest number of comparative observations. He has avoided some of the sources of error which were not provided against by Dutrochet, and has always been careful to operate with different solutions under conditions as nearly identical as possible. We can give the best definition of endosmotic equivalents by describing in detail the manner in which the experiments of Graham were performed.

The apparatus used was an endosmometer, made on the same principle as the instrument constructed by Dutrochet, but so modified as to obviate certain elements of inaccuracy in comparative experiments. The reservoir, or bulb, was three inches in diameter at the lowest portion, to which the membrane was applied, and its capacity was five or six ounces. To this was attached a vertical tube, six inches in length, with a calibre of about three-tenths of an inch, or one-tenth the diameter of the bulb. The membrane used was the bladder of the ox, with the muscular coat removed. Sometimes the membrane was doubled. To avoid the stretching of the membrane by pressure of liquid in the tube, it was supported by a slightly concave perforated zinc plate, carefully varnished, to prevent its being acted upon by the solutions, and resting on a tripod. This apparatus was filled with the solution up to a point marked zero on the vertical tube, and then placed in a jar containing about sixty ounces of distilled water, the surface of which was carefully brought to the level of the liquid in the tube.[1] In most of the com-

Fig. 8.

Instrument used by Graham for determining osmotic equivalents. (*Elements of Inorganic Chemistry*. Philadelphia, 1858, p. 749.)

[1] Graham, *On Osmotic Force.—Philosophical Transactions*, London, 1854, p. 185.

parative observations, the same membrane was used, being soaked for a number of hours in distilled water before each experiment. The tube was graduated in millimeters, and in each observation, the degrees of elevation or depression were noted hourly for five hours. When the principal current was from the exterior to the interior, the liquid in the endosmometer was said to be positively osmotic, and the number of degrees of elevation in the tube after immersion for five hours was taken as its osmotic equivalent. When, on the other hand, there was an excess in the diffusion of the liquid, it was said to be negatively osmotic, and the number of degrees of depression in the tube after immersion for five hours was taken as its negative osmotic equivalent.

With this apparatus, Graham determined the osmotic equivalents of a number of different solutions, the strength of each being one per cent. In the following table are given a few of these results:

Osmose of one per cent. Solutions in Membranes.[1]

Oxalic acid	— 148
Hydrochloric acid (0·1 per cent.)	— 92
Bichloride of tin	— 46
Chloride of sodium	+ 2
Chloride of potassium	+ 18
Chloride of calcium	+ 20
Sulphate of magnesia	+ 14
Protochloride of iron	+ 435
Chloride of mercury	+ 121
Mercuric nitrate	+ 476
Chloride of aluminium	+ 540
Carbonate of potash	+ 439

Experiments on the endosmotic power of different liquids have been very numerous, and some of them, particularly those referring to the endosmotic power of albumen, possess considerable physiological interest. The great endosmotic power of albumen, or the force with which albumen attracts

[1] GRAHAM, *Op. cit.—Philosophical Transactions*, London, 1854, p. 225, and *Elements of Inorganic Chemistry*, Philadelphia, 1858, p. 750.

liquids and causes them to pass through membranes, was early pointed out by Dutrochet;[1] and the experiments of Mialhe, to which we have already referred, have developed the interesting fact, that while albumen attracts liquids powerfully, it is not exosmotic.[2] The important applications of this fact to vascular absorption are evident.

Some of the modifications in the endosmotic currents, due apparently to very slight changes in the constitution of the liquids, show an influence exerted by these conditions which undoubtedly is capable of important applications to physiological absorption; but unfortunately, the ascertained facts bearing upon the subject are few and imperfectly understood. Dutrochet observed that the presence of a very small quantity of hydrosulphuric acid in a solution of gum or of sugar diminished very considerably the endosmotic action, by giving rise to a powerful exosmotic current from the acid to the water.[3] A still more remarkable fact was observed by Poiseuille. This observer filled an endosmometer with a solution of chloride of potassium, immersed it in serum, and noted quite a rapid elevation of the liquid to the height of nine millimeters; but on substituting for this a solution of the same density, to which the hydrochlorate of morphia had been added in the proportion of a little more than one per cent., the liquid rose only to the height of six millimeters, and there then followed a decided exosmotic current.[4]

As we have seen that there are various conditions capable of profoundly modifying physiological absorption, it will be interesting and useful to compare them with the physical and other conditions which influence endosmosis. In this way we will be enabled to appreciate more fully the appli-

[1] Dutrochet, *De l'Endosmose.—Mémoires*, Paris, 1837, p. 46.

[2] See page 477.

[3] Dutrochet, *op. cit.*, p. 64.

[4] Poiseuille, *Recherches Expérimentales sur les Médicaments.—Comptes Rendus*, Paris, 1844, tome xix., p. 1000.

cations of physical laws to the phenomena of absorption as it occurs in the living body.

Modifications of Endosmosis.

Modifications due to the Extent and Thinness of the Permeable Membrane.—It has been found in endosmotic experiments, that the activity of the currents is in proportion to the extent of the endosmotic surface and the thinness of the permeable membrane. In physiological absorption, the most favorable conditions for endosmosis are realized in the capillary system of highly vascular parts. The extent of absorbing surface is here enormous; and the walls of the vessels are exceedingly delicate and permeable. The experiments of Magendie and others on vascular absorption, which have already been considered in detail, demonstrate the great rapidity with which soluble substances are absorbed from the highly vascular mucous membrane of the intestinal canal; and the experiments upon absorption through the walls of the jugular vein show how much more slowly this takes place when the membrane is thick, and the surface comparatively restricted.[1]

Modifications due to Pressure and the Density of Liquids.—The force of the endosmotic current is frequently so great as to overcome a very considerable pressure. This is illustrated in all experiments in which the liquid in an endosmometer is made to rise in a long tube. If a closed membranous sac containing a highly endosmotic liquid be immersed in water, the force with which the liquid penetrates will often be sufficient to rupture the membrane itself; as is shown when an egg, with a part of its shell removed, is placed in water. This forcible character of the endosmotic current early attracted the attention of Dutrochet, whose experiments on this point were very interesting. He introduced into the reservoir of an endosmometer a saccharine

[1] See page 472.

solution of 1·035 density, charging his tube, which was bent in the form of a V, with a column of mercury one inch in height. At the end of twenty-eight hours, the ascent of the column of mercury was arrested at ten inches and seven lines. Using a saccharine solution of 1·070 density, and charging the tube with ten inches of mercury, in thirty-six hours, the elevation of the mercury had become arrested at twenty-two inches and ten lines. In a third experiment, the density of the saccharine solution was 1·040, and the tube was charged with twenty-two inches of mercury. The experiment lasted for three days, and the elevation of the mercury was forty-five inches and nine lines. All these experiments were made at the same temperature (69° Fahr.)[1]

These experiments, which have frequently been repeated in a more or less modified form, illustrate three points: first, the great force of the endosmotic current; second, the fact that this current may be arrested by a sufficient amount of pressure; for in the second experiment, after endosmosis had ceased and the mercury had been elevated nearly twenty-three inches, the density of the liquid in the endosmometer had been reduced from 1·070 to 1·053, when, without pressure, the current would undoubtedly have continued; and finally, these experiments illustrate the fact that, within certain limits, the force of the endosmotic current is in proportion to the concentration of the solution in the endosmometer.

Even in the large arteries, the pressure of blood seldom exceeds six inches of mercury, and it is much reduced when the blood passes into the capacious system of capillary vessels and thence into the veins. This amount of pressure, then, though capable of exerting a marked influence upon the rapidity of absorption, would not materially oppose the introduction of liquids of low density, even were its effects not counteracted to a certain extent by other circumstances; for it must be remembered that the blood has a specific

[1] DUTROCHET, *op. cit*, tome i., p. 38.

gravity of from 1·050 to 1·060, and contains salts and albumen, substances possessing highly endosmotic properties. Circulation of the blood is the most important condition modifying the opposing influence of pressure. This condition is so important in modifying endosmosis that it demands special consideration. It is sufficient in this connection, however, to appreciate the fact of its powerful influence in promoting the endosmotic current.

Variations in the pressure in the blood-vessels has already been alluded to as exerting an important influence on the rapidity of absorption. When the entire quantity of blood is diminished by hemorrhage or prolonged abstinence, the activity of endosmosis is immensely increased; and it is correspondingly diminished when the pressure is increased, as in plethora or after injection of fluids into the blood-vessels of a living animal. This rule does not apply to those instances of local increase in the pressure of blood which are attended with very great increase in the activity of the circulation, as in the mucous membrane of the intestinal canal during digestion and absorption.

In physical experiments, all observers have noticed a great increase in the activity of the currents with an increase in the density of the endosmotic solution. Graham found that with a solution containing two per cent. of sulphate of magnesia, the minimum of elevation in the tube of the endosmometer was 30, and the maximum 33 millimeters; with solutions containing five per cent. of the salt, the minimum was 73, and the maximum 76; with solutions containing ten per cent., the minimum was 134, and the maximum 152; and with solutions containing twenty per cent., the minimum was 238, and the maximum 283.[1]

These facts are directly applicable to the blood and the influence of the concentration of this fluid upon absorption.

[1] Graham, *op. cit.—Philosophical Transactions*, London, 1854, p. 199. These figures are selected from a large number of observations upon different saline solutions, all of which were followed by essentially the same results.

In physiological absorption, the salts of the blood exert a certain amount of endosmotic force, but of all its constituents, albumen is the most efficient in this regard. The greater the relative proportion of albumen to the watery constituents, the greater will be the activity of endosmosis. It is in this way that the hydragogue cathartics, by largely diminishing the watery constituents of the blood, at the same time that they diminish the pressure, increase the activity of absorption. The albumen of the blood also opposes exosmosis, or transudation; and when its proportion is considerably diminished, dropsies into the areolar tissue and the serous cavities are apt to occur.

Modifications due to Movements of the Liquids.—Movements of the liquids, in endosmotic experiments, are capable of increasing the activity of the currents in two ways. In the first place, by agitating the liquids the rapidity of diffusion is increased and fresh layers of liquid are brought in contact with the membrane. It is well known to all that have experimented on this subject, that in an ordinary endosmometer, after the current has become very feeble or has entirely ceased, it may be again excited by simply agitating the liquids. This fact was accurately described and explained by Poiseuille. He placed an endosmometer filled with a solution containing four per cent. of phosphate of soda in a vessel of serum. The liquid mounted in the tube to the height of thirty-four millimeters, but after some hours of complete repose, it descended to about three millimeters above the level of the external liquid. On slightly agitating the apparatus, the ascent recommenced at the rate of four millimeters per hour.[1] Poiseuille explains this fact on the principle that endosmosis and exosmosis had gone on in that portion of the liquid near the membrane until the density of the saline solution had been reduced to a point at which the

[1] POISEUILLE, *Recherches Expérimentales sur les Médicaments.—Comptes Rendus*, Paris, 1844, tome xix., p. 997.

current takes place in the opposite direction; as he had previously demonstrated that with one per cent. solutions of phosphate of soda, the current was always from the saline solution to the serum. This great diminution in density, however, he assumed to be only local; and the endosmotic current recommenced when general diffusion was hastened by agitation of the liquids. In experiments such as those performed by Matteucci and Cima, in which fluid is made to pass in a current through a portion of a vein which is immersed in a vessel of acidulated water, the rapid penetration of the acid is due in part to the suction force produced by the current, and in part to the constant renewal of liquid on one side of the membrane. In an experiment of this kind, Matteucci found that an acid reaction was almost immediately manifested in the liquid flowing from the vein when a current was established, but the penetration required some time when the liquids were motionless.[1]

In the vascular system, all the conditions are realized for the greatest development of the influence exerted upon endosmosis by the movements of liquids. The blood is circulating in the small vessels under a pressure much less than that in the general arterial system. It contains a large proportion of albumen, the fluid of all others which powerfully attracts an endosmotic current without itself passing through membranes. The circulation is so rapid that what enters through the walls of the vessels is immediately carried on to the heart, and in less than thirty seconds (the estimated duration of the entire circuit of the blood), by the churning action of this organ as well as the diffusion produced by the force of the current, is mixed with the whole mass of the circulating fluid. The substance absorbed must then modify the whole mass of blood (which is estimated at eighteen pounds, in a man of ordinary size) before the activity of absorption can be diminished by an alteration in the density of

[1] MATTEUCCI, *Leçons sur les Phénomènes Physiques des Corps Vivants*, Paris, 1847, p. 78.

the fluid toward which the current is directed. In ordinary absorption, this modification must be so slight as to have no material influence upon the endosmotic action.

Modifications due to Variations in Temperature.—The original experiments of Dutrochet developed some striking physical facts with regard to the influence of temperature on the endosmotic current, which have been repeatedly confirmed by later observers. In experiments with the cæcum of a fowl, filled with a solution containing one part of gum to ten of water, he found that the apparatus immersed in water at 41° Fahr. for an hour and a half gained thirteen grains in weight; while it gained twenty-three grains in the same time when the temperature of the water was raised to from 88° to 90°, notwithstanding the fact that the liquid had already become somewhat less endosmotic by the introduction of water in the first experiment.[1]

Under ordinary conditions, physiological absorption is not much influenced by temperature, for most of the liquids to be absorbed are soon brought to the general temperature of the body; but it is a general observation that warm liquids are absorbed more rapidly than cold.

Modifications induced by Electricity.—In a physical point of view, the influence of electricity upon the endosmotic current is very interesting; and it is impossible to say that this force does not intervene in the phenomena of absorption in the living body. Nevertheless, there are no sufficient data for assuming that physiological absorption has any thing to do with electricity; and it is much more reasonable to suppose that the modifications in absorption which are effected through the nervous system are due to the influence of the nerves upon the circulation.[2] In view of the early experiments of Porrett, who produced an endosmotic current

[1] DUTROCHET, *Mémoires*, etc., tome i., p. 27.
[2] See page 468.

through an animal membrane with pure water on either side, by simply immersing in the fluids the poles of a galvanic battery,[1] and the experiments of Dutrochet, who produced currents in the same way through the cæcum of the fowl,[2] the idea was advanced that all endosmosis was dependent upon galvanic action. No one, however, has ever professed to have detected a galvanic current during ordinary endosmosis, by the galvanometers usually employed, and this theory is without any positive basis.

These observations of Porrett and Dutrochet have been repeatedly verified by later experimenters. They showed a tendency to diffusion in two portions of the same liquid, separated by a membrane, when one was charged with positive and the other with negative electricity, the current taking place from the positive to the negative pole. Under these circumstances, the endosmotic current is actually produced by galvanic action, for it never takes place when the liquids on either side of the membrane are identical. Other experiments, which it is unnecessary to refer to in detail, have shown that the phenomena of osmosis between liquids of different constitution may be modified by galvanic action, that the currents may be established in this way where they would not otherwise take place, and that existing currents may be arrested or even reversed. The experiments of Fodera (which were made upon living animals before the description of endosmosis by Dutrochet), are striking examples of the influence of electricity upon the passage of solutions through animal membranes. This observer found that while it required from half an hour to an hour and a half for a solution of sulphate of iron and a solution of prussiate of potash, placed upon either side of an animal membrane, to penetrate its substance and produce the characteristic blue reaction, when the liquids were connected with the poles of a gal-

[1] PORRETT, *Curious Galvanic Experiments.—Annals of Philosophy*, London, 1816, vol. viii., p. 74.

[2] *Op. cit.*, p. 71.

vanic battery, this result was produced "in a few minutes and even in a few seconds, according to the power of the pile and the energy of its action." This is only one of a number of experiments by Fodera illustrating the influence of the galvanic current upon imbibition and absorption.[1]

The only definite applications of these facts to physiology have been made in connection with the influences of the nervous system upon absorption; and this has been done under the idea that there is something in common between the nervous force and electricity. If we are to determine the existence of electrical action by the usual methods, the galvanic current cannot be regarded as identical with nervous power. The only way which we have of detecting a galvanic current is by instruments known as galvanometers; and those used at the present day in accurate investigations are exceedingly sensitive. With the most delicate instruments known, it is impossible to detect any galvanic current during endosmosis, or during the conduction by nerves of the so-called nervous force. There is no reason, therefore, to suppose that absorption is affected by galvanic action operating through the nervous system, and we must be content with the explanations of nervous influence already given.[2] Nevertheless, galvanic currents have been detected between different tissues and different parts of the same tissue during life and immediately after death; but we have not as yet been able to determine positively the influence of these currents upon any of the important functions.

Applications of Physical Laws to the Function of Absorption.

In no experiments performed out of the body, can the conditions favorable to the passage of liquids through membranes in accordance with purely physical laws be realized as

[1] FODERA, *Recherches Expérimentales sur l'Absorption et Exhalation*, Paris, 1824, p. 22.

[2] See page 468.

they exist in the living organism. The vast extent of the absorbing surfaces; the great delicacy and permeability of the membranes; the rapidity with which principles are carried on by the torrent of the circulation, as soon as they pass through these membranes; the uniformity of the pressure, notwithstanding the penetration of liquids; all these favor the physical phenomena of absorption in a way which cannot be imitated in artificially constructed apparatus. It is not necessary to invoke the vital properties of tissues to explain the ordinary phenomena of absorption. Enough has been learned of the laws which regulated endosmosis and exosmosis to enable us to explain most of these phenomena upon physical principles. This fact has been apparent in studying these principles in their relation to absorption in the living body. But it is an important question to determine whether this be applicable to all the varied phenomena of physiological absorption. In other words, are there any modifications in this function which cannot, as yet, be explained by physical laws?

Admitting the fact that the general process of absorption takes place in accordance with the laws of endosmosis, we will now consider some of the phenomena which appear to be in opposition to known physical principles, or in which the application of these principles seems to be imperfectly understood.

It is not easy to understand how particles of emulsified fat find their way through the walls of the lacteals and the blood-vessels. The experiments of Matteucci with alkaline emulsions, which we referred to fully in connection with the absorption of fats, seem to show that alkalinity is a condition necessary to the penetration of fatty particles, though they do not offer an explanation of the mechanism by which these particles pass through membranes. It has been demonstrated that the epithelium which covers these membranes becomes filled with fatty granules during the absorption of emulsions, and we must invoke the aid of "cell-action,"—concerning

which it must be confessed that there exists very little definite information—in explanation of this phenomenon. The penetration of membranes by fatty particles must be regarded as one of the points which cannot be fully explained by the laws of endosmosis.

There are certain experiments on absorption in the living body, to which a great deal of importance was attached by Longet, which are seemingly in opposition to physical laws. This author states that when solutions of sugar of different densities are secured in isolated portions of the intestine of a living animal, the denser solutions are absorbed with as much rapidity as those which are less concentrated. He also shows that saline solutions of greater density than the blood are absorbed in the living animal, when, according to physical laws, the current should take place in the opposite direction.[1] The view that these facts are in opposition to physical laws is very successfully controverted by Milne-Edwards. This author, referring to some experiments by Von Becker in support of his position, asserts that there is first an exosmosis of the watery portions of the blood to these dense solutions, with a feeble penetration of the solutions into the blood-vessels, until, by the laws of diffusion, the solutions become so diluted as to be taken into the circulation.[2] Such an action as this could not take place between two saline solutions in an endosmometer, for both currents would cease when the liquids became of equal density; but it has been shown that after endosmosis in an endosmometer has ceased, it may be again induced by simply agitating the liquids. In physiological absorption, the motion is constant and very rapid, and solutions in their passage along the alimentary canal are continually exposed to fresh absorbing surfaces. Furthermore, the albumen of the blood, which is very slightly exosmotic, will attract an endosmotic current from liquids even when they are of the same density. The kind of ac-

[1] See page 464.

[2] MILNE-EDWARDS, *Leçons sur la Physiologie*, Paris, 1859, tome v., p. 192.

tion described by Milne-Edwards would be by no means an isolated example of a liquid passing out of the blood-vessels to be again absorbed after it has acted upon matters contained in the alimentary canal. This takes place with all the digestive fluids; and the liquid is effused, not by simple exosmosis, but by an act of secretion excited by the impression made upon the mucous membrane. We are not justified, therefore, in assuming, with Longet, that the absorption of solutions of greater density than the blood is always in opposition to the laws of endosmosis.

The imbibition of the coloring matter of the bile by the coats of the gall-bladder after death, while nothing of the kind takes place during life, is not due to the absence of vital action. During life, the circulation in the mucous membrane of this reservoir would readily remove the few particles of coloring matter which might penetrate from the bile, and of course there is no time for any coloration to take place.

In treating of the variations and modifications of absorption, we noted an apparent elective power in the mucous membrane of some portions of the alimentary canal. This is illustrated in the failure of the mucous membrane to absorb the woorara and various of the animal poisons, which, as a rule, are only effective when introduced into a wound or injected into the areolar tissue. The separation of various soluble substances by the process known as dialysis may throw some light upon this subject, but as yet we have no facts which offer a satisfactory explanation of this phenomenon.[1] Certain of these phenomena which show an apparent elective power in absorbing membranes are probably due to a cell-action resembling secretion; for all these surfaces are covered with epithelium, which must be penetrated before the fluids can get to the blood-vessels. But even with regard to the selection of materials from the blood to form secretions, very little of a definite character is known.

Those who believe that absorption is often modified by

[1] See page 477, note.

vital action offer this in explanation of the important influence of the nervous system on this function. Precisely how the nervous system affects absorption, in all instances, it is impossible in the present state of our knowledge to determine; but modifications are frequently effected through the sympathetic system. These nerves, as is well known, are capable of producing important local changes in the circulation, and can even temporarily arrest the capillary circulation in some parts; and it is in this way that many of the variations in absorption may be produced.

Transudation.—Although the endosmotic is the principal current in the functions which have thus far been considered, this is always accompanied by a certain amount of exosmosis. All the soft and vascular tissues, and all the cavities and tubes, contain a certain amount of exhaled or transuded fluid. This may be small in quantity and hardly more than vaporous, as it is over the pleura or peritoneum, or it may be liquid and in a decidedly appreciable quantity, like the intermuscular fluid, etc.; but all these vascular tissues are moistened by liquid which has transuded the permeable walls of the blood-vessels. The subject of transudation, however, is so closely connected with secretion, that its full consideration will come properly under that head, in another volume. At present it will be sufficient to notice only a few facts which relate to this subject. There is probably a feeble exosmotic current in the alimentary canal; which will account for the presence of certain salts, etc., in the fæces, which are evidently derived from the blood. In the subcutaneous areolar tissue and in the substance of and between the muscles, there is a certain quantity of a liquid containing a very minute proportion of albumen and some inorganic salts. This is transuded from the blood-vessels by so simple a process that it hardly merits the name of secretion.

Transudation of these liquids is influenced chiefly by the pressure of blood in the vessels and by the constitution of

the circulating fluid. The influence of pressure, which is so often observed in the dropsies which result from venous obstruction, was noted nearly two hundred years ago by Lower, who observed that there was a serous effusion under the skin of the face of a dog after the jugular veins had been tied.[1] This fact is too well established to need further illustration.

The influence of the constitution of the blood upon transudation is very interesting. The exosmotic properties of albumen are so slight, that there is usually but a very small amount of transudation through any of the vessels, and the fluid thus effused contains but a minute quantity of albumen; but if the density of the blood be greatly diminished, and especially if it become impoverished in albumen, transudation may become so active as to produce general dropsy. The deficiency in albumen in the blood of persons suffering from general dropsy was observed by Bostock, who, at the instance of Dr. Bright, made a number of examinations of the blood from patients suffering from what is now known as renal dropsy. "In the serum of these patients the proportion of albumen was found to be less than in health."[2] This fact has since been noted by other observers, particularly by Becquerel and Rodier, who made a large number of observations showing the influence of a deficiency of albumen in the blood upon transudation.[3] These facts have a pathological rather than a physiological bearing, but they illustrate the influence of the albumen of the blood upon normal transudation by exosmosis.

[1] Lower, *Tractatus de Corde, item de Motu et Colore Sanguinis, et Chyli in cum Transitu*, Amstelodami, 1669, p. 124.

[2] Bostock, *An Elementary System of Physiology*, London, 1827, p. 411.

[3] Becquerel et Rodier, *De l'Anémie par Diminution de Proportion de l'Albumine du Sang, et des Hydropsies qui en sont la Conséquence.—Extrait de la Gazette Médicale de Paris*, 1850.

CHAPTER XVII.

LYMPH AND CHYLE.

Mode of obtaining lymph—Quantity of lymph—Properties and composition of lymph—Alterations of the lymph—Influence of starvation upon the lymph—Corpuscular elements of the lymph—Leucocytes—Development of leucocytes in the lymph and chyle—Globulins—Origin and function of the lymph—Chyle—General properties of the chyle—Composition of the chyle—Comparative analyses of the lymph and the chyle—Microscopical characters of the chyle—Movement of the lymph and the chyle—Pressure of fluids in the lymphatic system—General rapidity of the lymphatic circulation—Causes of the movement of the lymph and chyle—Influence of the forces of endosmosis and transudation—Influence of the contractile walls of the vessels—Influence of pressure from surrounding parts—Influence of the movements of respiration.

To complete the history of physiological absorption, it will be necessary to study carefully the origin, composition, and properties of the lymph and chyle. It is only within a few years that physiologists have been able to appreciate the importance of the lymph, for the experiments indicating the enormous quantity of this liquid which is continually passing into the blood are of recent date. The earlier experimenters never succeeded in obtaining more than a small quantity of fluid from the lymphatic system. On the other hand, for the long period during which it was supposed that all the products of digestion entered the system by the thoracic duct, the importance of the chyle was much exaggerated; but the researches upon intestinal absorption by Magendie and those who followed him, and the experiments of Colin on the quantity of fluid which passes into the blood by the thoracic duct during the intervals of digestion, have

enabled physiologists to form a better estimate of the importance of the lymph and chyle. In studying the properties of these fluids, the consideration of the lymph naturally precedes that of the chyle; as the latter consists simply of lymph, to which certain of the products of digestion have been added during absorption from the alimentary canal.

Lymph.

Mode of obtaining Lymph.—The old methods of obtaining this fluid are no longer employed. In the inferior animals, recently killed, a few drops may be obtained by pricking the lymphatic glands, or by exposing the right lymphatic trunk or the thoracic duct, and collecting the small quantity of fluid which is discharged when these vessels are punctured. Although a notable quantity of chyle can be obtained from the thoracic duct of an animal killed during intestinal absorption, it is difficult to collect even a small quantity of fluid during the intervals of digestion. Various occasions have presented themselves for obtaining lymph, possessing more or less of its normal characters, from the human subject during life; but in many of these instances, as in the observations of Wutzer, Sömmerring, Nasse, Marchand and Colberg, and some others, there existed some pathological condition of the lymphatic system, and it cannot be assumed that the liquid thus obtained was in a perfectly healthy condition.

The first successful experiments in which the lymph and chyle were obtained in quantity were made by Colin. This observer, in operating upon large animals, particularly the ruminants, experienced no great difficulty in isolating the thoracic duct near its junction with the subclavian vein, and introducing a metallic tube of sufficient size to allow the free discharge of fluid.[1] These experiments, made upon horses

[1] Colin, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 100.

The idea of establishing a fistula into the thoracic duct did not originate with Colin, although he was the first to perform the experiment successfully. In the

and the larger ruminants, were the first to give any clear idea of the quantity of liquids—lymph and chyle—which pass through the thoracic duct. In an observation upon a cow of medium size, he succeeded in collecting, in the course of twelve hours, the enormous quantity of 105·3 lbs. av. (47,963 grammes); and he further states that a very much greater amount can be obtained by operating upon ruminants of larger size.[1] Whether this represents the actual quantity which is normally discharged into the venous circulation is a question which will be considered under the head of the probable quantity of lymph and chyle; but it certainly shows that the lymph cannot but be regarded as one of the most important of the animal fluids.

Among the observations upon the fluids discharged from the thoracic duct which followed the experiments of Colin, the most interesting are those made in 1859, by Dalton, who operated upon carnivorous as well as herbivorous animals. These experiments were performed upon young goats and dogs; and the general results with regard to the quantity of fluids discharged closely corresponded with those obtained by Colin.[2] The operation of making the fistula in goats is not very difficult, all that is necessary being to cut down upon the subclavian vein at the point where the duct

latter part of the last century, Flandrin, who made a number of experiments upon the effects of ligating the thoracic duct in horses (see page 449), attempted to make a fistula into the canal by exposing it and introducing a tube made of tin. He did not succeed, however, in obtaining the chyle in quantity, as the tube soon became obstructed. (FLANDRIN, *Suite des Expériences sur l'Absorption des Vaisseaux Lymphatiques dans les Animaux.—Journal de Médecine, Chirurgie, Pharmacie*, etc., Paris, 1791, tome lxxxvii., p. 230 *et seq.*)

[1] COLIN, *op. cit.*, tome ii., p. 106.

[2] DALTON, *The Physiology of the Circulation.—A Course of Lectures delivered in the College of Physicians and Surgeons, New York, in the Fall Term of* 1859.—*American Medical Monthly and New York Review*, December, 1860, p. 415; and *Treatise on Human Physiology*, Philadelphia, 1864, p. 322.

Dr. Dalton, in his experiments upon dogs, poisoned the animals with woorara, and collected the liquid which flowed from the thoracic duct, the circulation being kept up by artificial respiration.

empties into it, and fix in it a tube of appropriate size; but in dogs, the vessels are more deeply situated, and the operative procedure is much more tedious. This, however, is the only way in which lymph and chyle can be obtained from the lower animals in any considerable quantity.

Quantity of Lymph.—Although the experiments just described might at first seem sufficient to give a pretty clear idea of the entire quantity of lymph discharged into the venous system, it is evident that the conditions of the circulation of this fluid must be so seriously modified by the establishment of a fistula, that the results thus obtained are far from being entirely satisfactory. In the first place, Colin found that the canal, at its junction with the subclavian vein, was seldom single; and in many of his observations in which a very large quantity of liquid was obtained, there were several vessels of nearly equal size emptying into the venous system. In the experiment which we have referred to, however, the opening was single; and the quantity of fluid obtained represented all that passed up the thoracic duct during the time that the observation was continued. As we should naturally expect, the discharge of liquid was subject to certain variations, its maximum corresponding with the period of greatest activity in digestion and absorption.

It is not possible to estimate the influence of the unobstructed discharge of lymph and chyle by a fistulous opening upon the absolute quantity which passes out of the canal; and in the natural course of the circulation, there is a certain amount of obstruction to its entrance into the vein, which might sensibly retard the current.

According to the estimates of Dalton, deduced from his own observations upon dogs and the experiments of Colin upon horses, the total quantity of lymph and chyle produced in the twenty-four hours in a man weighing one hundred and forty pounds is from six to six and a half pounds. And,

again, reasoning from experiments made upon dogs eighteen hours after feeding, when the fluid which passes up the thoracic duct may be assumed to be pure unmixed lymph, the total quantity of lymph alone, produced in the twenty-four hours by a man of ordinary weight, would be between three and a half and four pounds (3·864 lb.).[1] These estimates can only be accepted as approximative; and they do not indicate the entire quantity of lymph actually contained in the organism.

There are no very late researches with regard to the variations in the quantity of lymph. Collard de Martigny made a series of elaborate investigations a number of years ago, with regard to the effects of starvation upon the constitution and the quantity of the lymph. He found the lymphatics always distended with fluid in dogs killed after two days of total deprivation of food. This condition continued during the first week of starvation; but after that time, the quantity in the vessels gradually diminished, and a few hours before death, the lymphatics and the thoracic duct were nearly empty. In comparing the quantity of fluid in the lymphatics of the neck during digestion and absorption, with the quantity which they contained soon after digestion was completed, the same observer found that while digestion and absorption were going on actively, the vessels of the neck contained scarcely any fluid; but the quantity gradually increased after these processes were completed.[2]

Properties and Composition of Lymph.—Lymph taken from the vessels in various parts of the system, or the fluid which is discharged from the thoracic duct during the intervals of digestion, is either perfectly transparent and color-

[1] DALTON, *Treatise on Human Physiology*, Philadelphia, 1864, p. 322.

[2] COLLARD DE MARTIGNY, *Recherches Expérimentales sur les Effets de l'Abstinence Complète d'Alimens solides et liquides sur la Composition et la Quantité du Sang et de la Lymphe.—Journal de Physiologie*, Paris, 1828, tome viii., p. 174 *et seq.*

less, or of a slightly yellowish or greenish hue. When allowed to stand for a short time, it becomes slightly tinged with red; and frequently it has a faint rose-color when first discharged. Miscroscopical examination shows that this reddish color is dependent upon the presence of a few blood-corpuscles, which are entangled in the clot as the lymph coagulates, thus accounting for the deepening of the color when the fluid has been allowed to stand. The origin of these red corpuscles has long been a subject of discussion. Their constant presence in lymph or chyle discharged by fistulous openings has led to the opinion that they are normal constituents of these fluids; and this view has been adopted without reserve by those who assume that the blood-corpuscles are formed from the white corpuscles, or leucocytes. If this view of the formation of the corpuscular elements of the blood be adopted, there is no good reason why red corpuscles should not be formed from the leucocytes in the lymph and chyle as well as in the blood itself; particularly as the clear fluid of the lymph and chyle contains nearly all the principles found in the plasma of the blood. On the other hand, many regard the presence of red corpuscles as always accidental; and in support of this view, Robin brings forward the fact that red corpuscles are never found in lymph taken from a portion of a vessel included between two ligatures.[1] This is certainly a very strong argument against the constant and normal existence of red corpuscles in the lymph, particularly as the connection between the lymphatics and the blood-vessels is very close, and all operations upon the lymphatic system involve disturbances in the circulation. There is no positive evidence of the formation of red corpuscles from the leucocytes; and if it be the fact that red corpuscles never exist in lymph taken from a portion of a lymphatic vessel included between two ligatures, it is fair to assume that the presence of these corpuscles in lymph and chyle is

[1] ROBIN, *Programme du Cours d'Histologie professé à la Faculté de Médecine de Paris*, 1862–'63, *et* 1863–'64, Paris, 1864, p. 112.

accidental, and that they are always derived from the blood.

Lymph has no decided or characteristic odor. It is very slightly saline in taste,—almost insipid. Its specific gravity is very much inferior to that of the blood. Magendie found the specific gravity in the dog to be about 1,022.[1] Robin states that the specific gravity of the defibrinated serum of the lymph is 1,009.[2] In some recent analyses, by Dähnhardt, of the lymph taken from dilated vessels in the leg, in the human subject, the specific gravity was only 1,007.[3] The exceedingly low specific gravity in the last instance would rather lead to the opinion that the fluid was not entirely normal. The difficulty in obtaining this fluid in a perfectly normal condition from the human subject has rendered it impossible to ascertain its normal specific gravity, even approximatively; but it evidently possesses a density much inferior to that of the blood. The reaction of the lymph is constantly alkaline. According to Robin, the alkalinity of the lymph is neutralized by 0·37 per cent. of lactic acid, while the blood is neutralized by 0·50 per cent.[4]

A few minutes after discharge from the vessels, both the lymph and chyle undergo spontaneous coagulation. According to Colin, the fluid collected from the thoracic duct in the large ruminants coagulates at the end of five, ten, or twelve minutes, and sets into a mass having exactly the form of the vessel in which it is contained. Colin states that the clot is tolerably consistent, but that there is never any spontaneous separation of serum.[5] This may be the fact with regard to the lymph and the chyle of the large ruminants, but in the observations of Dalton, who operated upon dogs and goats,

[1] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 192.

[2] ROBIN, *Programme du Cours*, Paris, 1846, p. 111.

[3] DÄHNHARDT, *Zur Chimie der Lymphe*.—VIRCHOW'S *Archiv*, Berlin, 1866, Bd. xxxvii., S. 59.

[4] *Loc. cit.*

[5] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 111.

after a few hours' exposure, the clot contracted to about half its original size, precisely like coagulated blood, and the serum became perfectly separated. In one instance, in the dog, the volume of serum, after twenty-four hours of repose, was about twice that of the contracted clot.[1] Milne-Edwards, quoting from an unpublished memoir presented by Colin to the Academy of Sciences, in 1858, states that the lymph does not coagulate in the vessels, even when the circulation is interrupted.[2] This may be the case under ordinary conditions, when the vessels are simply tied; but it was found by Flandrin,[3] that coagulation obstructed the tubes which he introduced into the thoracic duct so completely that he was able to obtain but a small quantity of fluid; a difficulty which is also mentioned by Colin, who states that "the clearing of the tube rarely suffices to reëstablish the flow, for the coagulum formed in the tube is prolonged for a greater or less distance into the interior of the thoracic duct."[4] Coagulation of lymph in the vessels during life, if it occur at all, must be exceedingly infrequent, notwithstanding that the flow of lymph and chyle is very slow and irregular, compared with the circulation of the blood, and is subject, probably, to frequent interruptions.

Although numerous analyses have been made of lymph from the human subject, the conditions under which the fluid has been obtained render it probable that in the majority of instances it was not entirely normal. It will be necessary, therefore, to compare these analyses with observations made upon the lymph of the inferior animals; as in the latter, this fluid has been collected under conditions which leave no doubt as to its normal character. In the experiments of

[1] Dalton, *Lectures on the Physiology of the Circulation.—The American Medical Monthly and New York Review*, December, 1860, p. 411.

[2] Milne-Edwards, *Leçons sur la Physiologie*, Paris, 1859, tome iv., p. 556, note

[3] *Loc. cit.*

[4] Colin, *op. cit.*, tome ii., page 111.

Colin especially, the fluids taken from the thoracic duct during the intervals of digestion undoubtedly represent the normal mixed lymph collected from nearly all parts of the body; and the operative procedure in the large ruminants is so simple as to produce little if any general disturbance. The following is an analysis by Lassaigne of specimens of lymph collected by Colin from the thoracic duct of a cow, under the most favorable conditions:

Composition of Lymph from a Cow.[1]

Water	964·0
Fibrin	0·9
Albumen	28·0
Fatty matter	0·4
Chloride of sodium	5·0
Carbonate, phosphate, and sulphate of soda	1·2
Phosphate of lime	0·5
	1,000·0

These proportions are by no means invariable, the differences in coagulability indicating differences in the proportion of fibrin, and the degree of lactescence showing great variations in the proportion of fatty matters. The table may be taken, however, as a pretty close approximation of the average composition of the lymph of these animals, during the intervals of digestion.

Of the various analyses of human lymph, it will be necessary only to select a few, as most of them are far from

[1] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 111.

The proportions in this table have been changed from hundreds to thousands. In this, as in all other analyses of the lymph, the organic constituents are estimated dry. In treating of the composition of the blood (see vol. i., p. 130 *et seq.*), we endeavored to show that the water which exists in coagulated fibrin and albumen should be considered as water of composition; coagulation simply altering the form of these organic principles without changing their constitution. According to this view, an estimate of these substances in a dry state gives the quantity of the residue after desiccation, and not their actual proportion in a natural condition.

representing the normal characters of this fluid. Lhéritier analyzed the contents of the thoracic duct of a man who died of softening of the brain, having taken a little water thirty hours before death.[1] This analysis gives a very large proportion of fibrin, albumen, and fatty matters (3·20 of fibrin, 60·02 of albumen, and 5·10 of fat, per 1,000), so large, indeed, that some physiologists doubt the accuracy of the results.[2] On the other hand, the analyses of Marchand and Colberg,[3] which are so often quoted, give, as the composition of lymph extracted from a wound of the lymphatics on the top of the foot, a very large proportion of water (969·26 parts per 1,000), and consequently a small proportion of solid matter. We would suppose that fluid thus taken from a wounded part must necessarily contain an admixture of pathological secretions.

The analyses of human lymph which seem to be the most reliable, and in which the fluid was apparently pure and normal, are those of Gubler and Quévenne. The lymph, in this case, was collected by Desjardins from a female who suffered from a varicose dilatation of the lymphatic vessels in the anterior and superior portion of the left thigh. These vessels occasionally ruptured, and the lymph could then be obtained in considerable quantity. When an opening existed, the discharge of fluid could be arrested at will by flexing the trunk upon the thigh. Gubler and Quévenne made elaborate analyses of two different specimens of the fluid, with the following results.[4]

[1] Becquerel et Rodier, *Traité de Chimie Pathologique*, Paris, 1854, p. 3.

[2] Longet, *Traité de Physiologie*, Paris, 1861, tome i., p. 411.

[3] Marchand und Colberg, *Ueber die chemische Zusammensetzung der menschlichen Lymphe.*—Poggendorff's *Annalen der Physik und Chemie*, Leipzig, 1838, Bd. cxix., S. 629.

[4] Desjardins, *Note sur un Cas de Dilatation variqueuse du Réseau Lymphatique superficiel du Derme; Émission volontaire de Lymphe; Analyse de cette Lymphe, par* Gubler et Quévenne.—*Gazette Médicale de Paris*, 1854, p. 454.

The two tables of Gubler and Quévenne have been brought together and the proportions changed from hundreds to thousands. An evident error in the second analysis (9·92 instead of 0·92 parts of fatty matter per hundred) has been corrected. For a full account of this case, with the analyses and examinations of

Composition of Human Lymph.

	First Analysis.	Second Analysis.
Water	939·87	934·77
Fibrin	0·56	0·63
Caseous matter (with earthy phosphates and traces of iron)	42·75	42·80
Fatty matter (in the second analysis, fusible at 102·3° Fahr.)	3·82	9·20
Hydro-alcoholic extract (containing sugar, and leaving, after incineration, chloride of sodium, with the phosphate and the carbonate of soda)	13·00	12·60
	1,000·00	1,000·00

The above analyses show a much larger proportion of solid constituents than was found by Lassaigne in the lymph of the cow. This excess is pretty uniformly distributed throughout all the constituents, with the exception of the fatty matters and fibrin; the former existing largely in excess in the human lymph, especially in the second analysis, while the latter is smaller in quantity than in the lymph of the cow. It is evident, however, from a comparison of the two analyses of Gubler and Quévenne, that the composition of the lymph, even when it is unmixed with chyle, is subject to great variations. The caseous matter given by Gubler and Quévenne is probably equivalent to the albuminous matter of other chemists.

The distinctive characters of the different principles found in the lymph do not demand extended consideration, inasmuch as most of them have already been treated of in connection with the blood. In comparing, however, the composition of the lymph and the blood, we are at once struck with the great excess of solid constituents in the latter fluid. In the analyses of the serum of the blood by Becquerel and Rodier, the proportion of solid constituents was ninety-two parts per 1,000;[1] while in the analyses of the hu-

the fluid, the reader is referred to the *Gazette Médicale*, 1854, pp. 361, 403, 452, and 516.

[1] BECQUEREL ET RODIER, *Chimie Pathologique*, Paris, 1854, p. 86.

man lymph by Gubler and Quévenne, the proportion was from sixty to sixty-five parts per 1,000, and in the analysis of Lhéritier, which gives the largest quantities of solid matter, the proportion was between seventy-five and seventy-six parts.[1]

In all analyses, except those of Lhéritier, the organic nitrogenized compounds have been found to be very much less in the lymph than in the blood. This is generally most marked with regard to the fibrin; but, as before stated, the proportion of all these ingredients is quite variable. On ac-

[1] A series of very elaborate analyses of the human lymph has recently been made by Dähnhardt, under the direction of Professor Hensen. The fluid was collected from a patient suffering from elephantiasis, or some analogous affection, in which the lymphatics were found dilated. These observations have already been referred to, and it is probable that the fluid obtained was not normal lymph. The analyses, however, were exceedingly minute, especially as regards the proportions of inorganic matters. The following is one of the analyses of this fluid:

Water		987·700
Fat		0·030
Organic extractives soluble in alcohol		1·284
Organic extractives soluble in water = extractive and albumen		0·908
Organic substances insoluble in water = fibrin and insoluble albumen.		1·699
Inorganic substances soluble in water,	Chloride of sodium	6·148
	Soda	0·576
	Potash	0·493
	Carbonic acid	0·638
	Sulphuric and phosphoric acid and loss,	0·221
Inorganic substances insoluble in water,	Chalk	0·132
	Magnesia	0·011
	Oxide of iron	0·006
	Phosphoric acid	0·118
	Carbonic acid	0·015
	Carbonate of magnesia, sulphuric acid, and loss	0·021
		1,000·000

—Dähnhardt, *Zur Chemie der Lymphe.*—Virchow's *Archiv*, Berlin, 1866, Bd. xxxvii., S. 55 *et seq.*

Analyses of the same lymph for organic matter, by Professor Hensen, give a proportion of 1·070 of fibrin, 1·408 of serum-albumen, and 0·894 of albuminous compounds precipitated by acetic acid.

count of this deficiency in fibrin, lymph is much inferior to the blood in coagulability, and the coagulum, when it is formed, is soft and friable. There does not appear, however, to be any actual difference between the coagulating principle of the lymph and the fibrin of the blood.

Lassaigne found, in the lymph of the cow, that the quantity of albumen was a little less than one-half the proportion contained in the blood; but in most analyses of human lymph, the proportion has been much less. The analyses of Gubler and Quévenne, however, give a somewhat greater quantity of albuminoid matter (caseous matter), the proportion in one analysis being 42·75, and in the other 42·80 parts per 1,000. There appears, also, to be some difference between the albuminoid matter of the lymph and the albumen of the blood. Gubler and Quévenne speak of the substance found in one lymph as caseiform matter; and Hensen speaks of a proportion of serum-albumen and of albuminous matter precipitated by acetic acid. The albuminoid matter of the lymph, therefore, would seem to possess certain distinctive characters; but we know so little of the function of this fluid, that it is impossible to assign to these substances any special physiological properties.

Fatty matters have generally been found more abundantly in the lymph than in the blood; but their proportion is even more variable than that of the albuminoid substances.

Very little remains to be said concerning the ordinary inorganic constituents of the lymph. The analyses of Dähnhardt have shown that nearly, if not all, of the inorganic matters which have been demonstrated in the blood are contained in the lymph; and even a small proportion of iron is given in the analyses of Gubler and Quévenne.

These facts indicate a remarkable correspondence between the composition of the lymph and that of the blood. All of the constituents of the blood exist in the lymph, the only difference being in their relative proportions. It is the same with the corpuscular elements; for the so-called lymph-

corpuscles are identical with the leucocytes of the blood, and the red disks frequently find their way from the blood-vessels into the lymphatics.

In addition to the constituents of the lymph ordinarily given, the presence of glucose, and more lately, the existence of a certain proportion of urea, have been demonstrated in this fluid. Brande, in 1812, noted the presence of sugar in the chyle, but not in the lymph.[1] It has since been demonstrated, however, in the lymph, by Gubler and Quévenne,[2] Poiseuille and Lefort,[3] Colin,[4] and others. Poiseuille and Lefort found that the proportion of sugar was always greater in the lymph than in the chyle. The recent researches of Colin show that the difference between the proportion of this substance in the lymph and in the chyle is not very great, and its quantity does not vary very considerably in different classes of animals. His observations were made upon horses, oxen, and dogs, and the proportion of sugar varied between 1·02 and 1·58 parts per 1,000.[5] It has not been ascertained how the sugar contained in the lymph takes its origin, and its function in this situation is equally obscure.

The presence of urea in considerable quantity in both the chyle and the lymph has been determined by Wurtz;[6] and it is thought by Bernard that the lymph is the principal

[1] Brande, *Chemical Researches on the Blood and some other Animal Fluids.—Philosophical Transactions*, London, 1812, p. 96.

Brande noticed crystals of what he supposed to be sugar of milk in the alcoholic extract of the fluid taken from the thoracic duct four hours after feeding.

[2] Gubler et Quévenne, *op. cit.—Gazette Médicale de Paris*, 1854, p. 454. These observers, while admitting that the existence of sugar in the lymph is rendered exceedingly probable—as the extract reduced a copper solution—did not assume to have positively demonstrated its existence.

[3] Poiseuille et Lefort, *De l'Existence du Glycose dans l'Organisme Animal.—Comptes Rendus*, Paris, 1858, tome xlvi., p. 567, and *Note supplémentaire*, Ibid., p. 678

[4] Colin, *De l'Origine du Sucre contenu dans le Chyle.—Journal de la Physiologie*, Paris, 1858, tome i., p. 539 *et seq.*

[5] *Loc. cit.*, p. 544.

[6] Bérard, *Formation Physiologique du Sucre dans l'Économie Animale.—*

fluid, if not the only one, by which this excrementitious substance is taken up from the tissues.[1] Although urea always exists in the blood, its quantity is less than in the lymph.[2]

The pathological alterations of the lymph have not been experimentally investigated, if we except the early observations of Collard de Martigny upon the effects of abstinence upon the composition of this fluid. The experiments of this observer upon the effects of abstinence upon the quantity of lymph have already been referred to.[3] With regard to the influence of this condition upon the composition of the lymph, we may take the results of three analyses of the fluid from dogs that had been without food, respectively, for thirty-two hours, nine days, and twenty-one days.[4]

	After 32 hours.	After 9 days.	After 21 days.
Water and salts	940·0	931·4	936·8
Fibrin	3·0	5·8	3·2
Albumen, fatty, and coloring matters.	57·0	62·8	60·0

Bulletin de l'Académie Impériale de Médecine, Paris, 1856–'57, tome xxii., p. 784.

Wurtz discovered urea in a specimen of chyle brought to him by Bérard for examination, taken from a young bull. In less than a gramme of chyle, he discovered large quantities of urea, and formed distinct crystals by combining it with nitric acid. He believed that the urea came from the lymph and not from the alimentary substances taken up from the intestine. This view was confirmed by subsequent analyses, in which he discovered urea in the lymph of the dog, the horse, and the ox. He found also that its proportion in the lymph was greater than that naturally contained in the blood. (Written communication, in LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 429, note.)

[1] BERNARD, *Leçons sur les Propriétés Physiologiques et les Altérations Pathologiques des Liquides de l'Organisme*, Paris, 1859, tome ii., p. 27.

[2] Wurtz, analyzing comparatively the blood, lymph, and chyle for urea, found this substance in greatest proportion in the lymph. In a dog nourished with meat, the proportion of urea was 0·089 parts per 1,000 in the blood and 0·158 in the lymph; in a cow, the proportion was 0·192 in the blood, 0·192 in the chyle, and 0·193 in the lymph; and in a ram, the proportion was 0·248 in the blood, and 0·280 in the chyle. (*Comptes Rendus*, Paris, 1859, tome xlix., p. 53.)

[3] See page 511.

[4] COLLARD DE MARTIGNY, *Recherches Expérimentales sur les Effets de l'Abstinence complète d'Alimens solides et liquides, sur la Composition et la Quantité du Sang et de la Lymphe.—Journal de Physiologie*, Paris, 1828, tome viii., p. 182 *et seq.*

This table shows a certain concentration of the lymph during the first periods of starvation; but when the vital powers had become very much reduced, and death became imminent, conjoined with a great diminution in the absolute quantity of the lymph there was a notable reduction in the proportion of its solid constituents.

The differences which the lymph presents in different vessels relate chiefly to the abundance of its corpuscular elements. It has been said, however, that the quantity of fibrin is greatest in the contents of the thoracic duct, and that its proportion progressively increases from the periphery to the large vessels.[1] There is no positive evidence, however, that fibrin is produced by the lymphatic glands, though this theory has been advanced.

Corpuscular Elements of the Lymph.—In every part of the lymphatic system, in addition to a few very minute fatty granules, there are found certain corpuscular elements known as the lymph-corpuscles. These exist, not only in the clear lymph, but in the opaque fluid contained in the lacteals during absorption. They are now regarded as identical with the colorless globular corpuscles found in the blood, known under the name of white blood-corpuscles, or leucocytes. Although these bodies have been pretty fully described in treating of the corpuscular elements of the blood,[2] they present some peculiarities in the lymphatic system, particularly in their development, which demand consideration.

The leucocytes found in the lymph and chyle are rather less uniform in size and general appearance than the white corpuscles of the blood. Their average diameter is about $\frac{1}{2500}$ of an inch; but some are larger, and others are as small as $\frac{1}{5000}$ of an inch. Some of these corpuscles are quite clear and transparent, presenting but few granulations and an indistinct nuclear appearance in their centre; but others are

[1] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 413.
[2] See vol. i., p. 121.

granular and quite opaque. They present the same adhesive character in the lymph that we have noted in the blood, and frequently are found collected in masses in different parts of the lymphatic system.[1] Treated with acetic acid, the corpuscles generally become swollen, and are rendered very transparent, then presenting from one to four or five nuclear concretions in their interior. In all other regards, these bodies present the same characters as the leucocytes of the blood, and need not, therefore, be further described.

We have already alluded to the fact that the lymph-corpuscles are more abundant in the larger than in the smaller vessels; and that they have been thought to be particularly numerous in the vessels coming from the lymphatic glands. It is nevertheless true that corpuscles exist even in the smallest vessels, and they are sometimes quite abundant in lymph which has not passed through any glands. These considerations naturally lead to the theory of the development of leucocytes in the lymphatics, as well as in the ordinary vascular system, particularly as the constant discharge of lymph and chyle into the blood-vessels renders it more than probable that most of the leucocytes found in the blood are derived from the lymph.

The late researches of Robin, and others, by whom his observations have been somewhat extended, have conclusively demonstrated that leucocytes may be developed, under proper conditions, in a clear structureless blastema, without the intervention of any glandular organ; and, furthermore, it is not necessary that the blastema should be enclosed in any system of vessels. These facts refute completely the idea that the lymph-corpuscles are formed either by the lymphatic glands or by the walls of the lymphatic vessels. Observations have also shown that leucocytes exist in the blood of the embryo before any lymphatic vessels can be demon-

[1] Robin, *Sur quelques Points de l'Anatomie et de la Physiologie des Leucocytes ou Globules blancs du Sang.*—*Journal de la Physiologie*, Paris, 1859, tome ii., p. 44.

strated;[1] a fact which shows that these bodies may be developed *de novo* in the blood-plasma.

Of these facts there can be no doubt; and since the publication of the first volume of this work, additional experiments upon the development of leucocytes in clear fluids have not only confirmed the views which we adopted with regard to the origin of these bodies in the blood and elsewhere, but have defined more closely the conditions under which such development may take place. We refer particularly to the observations of Onimus upon the genesis of leucocytes and upon spontaneous generation.[2] These experiments are all the more striking in their application to the development of the lymph-corpuscles, as they were made with the clear fluid effused from the blood by vesication, and as recent facts with regard to the relative anatomy of the smallest lymphatics and the blood-vessels render it probable that the lymph is in great part derived from liquid elements which pass out of the blood by exosmosis.

Onimus used the clear fluid taken without delay from rapidly developed blisters, which he found ordinarily contained no leucocytes, but which he carefully filtered in order to remove all sources of error. The filtered liquid contained no morphological element whatsoever; but, on the other hand, he found that if the liquid were allowed to remain for an hour or more in contact with the dermis, it always contained leucocytes and epithelial cells. Under these circumstances, even after filtration, the liquid contained a few leucocytes; but after six or seven hours of repose in a conical vessel, the corpuscular elements gravitated to the bottom, leaving the upper portion of the liquid perfectly clear.

This liquid, entirely free from formed anatomical elements, was enclosed in little sacs formed of an animal mem-

[1] Robin, *op. cit.—Journal de la Physiologie*, Paris, 1859, tome ii., p. 49.

[2] Onimus, *Expériences sur la Genèse des Leucocytes et sur la Génération Spontanée.—Journal de l'Anatomie et de la Physiologie*, Paris, 1867, tome iv., p. 47 *et seq.*

brane (goldbeater's skin) and introduced under the skin of a living rabbit. At the end of twelve hours, a few small leucocytes and granulations had made their appearance; at the end of twenty-four hours, the fluid had become somewhat opaque and contained a large number of leucocytes and granulations; and at the end of thirty-six hours, the fluid was white, milky, and composed almost entirely of leucocytes and granulations. The leucocytes, which were examined also by Robin, presented all the characters by which these corpuscles are ordinarily recognized. These experiments were repeated with more than forty different specimens of fluid from blisters.

The experiments were then varied in order to show the influence of the membrane and of the composition of the blastema upon the development of leucocytes. By modifying the membrane in which the blastema was enclosed, it was found that the corpuscles were rapidly developed in proportion to the activity of the osmotic action. When thick animal membranes were used, their development was slow, and in some instances did not take place at all. There was no development of leucocytes in a clear blastema enclosed in a sac of caoutchouc or in glass tubes hermetically sealed; and from this it was concluded that the osmotic action was a necessary condition, and that the mere heat of the body was not sufficient to develop these corpuscles, even in an appropriate blastema. The influence of this constant molecular movement is in striking contrast to the conditions of absolute repose which are so essential to the formation of crystals from ordinary saline solutions.

One of the most interesting points in these experiments is connected with the influence of the composition of the blastema upon the development of leucocytes. It was found that these bodies were never developed in a blastema in which the fibrin had been coagulated. Experimenting with two liquids, the only difference in their constitution being that in one the fibrin had been coagulated by repeatedly

plunging the glass tube in which it was contained into coo water, while the other was kept at the ordinary temperature, a little bicarbonate of soda being added to prevent coagulation, it was found that leucocytes were developed as usual in the fluid which contained its fibrin, and that none appeared in the other. On placing the liquid with its coagulum enclosed in a sac under the skin, it was found that after a time the fibrin was redissolved, but no leucocytes made their appearance.

The theory which has for its motto, *omnis cellula e cellula*, receives no support from these experiments. Onimus added to fluids which had been deprived of their fibrin, epithelial cells and pus-corpuscles, but even after thirty-six hours, he never found any additional development of corpuscular elements. Leucocytes added to fluids in which the fibrin was unchanged did not seem to exert any influence upon the development of new corpuscles.

As regards the lymph, there is no fluid in the body which is placed under conditions more favorable to the development of leucocytes. It is enclosed in a system of vessels possessing extremely thin walls, and undoubtedly subjected to active osmotic currents. It contains, likewise, a considerable quantity of fibrin; and the proportion of this principle has always been found to influence the rapidity of the development of white corpuscles. Its circulation is not very rapid, and the obstacles to the current which are presented in the lymphatic glands undoubtedly give time for the perfection in the structure of leucocytes. It is in this way that the increase in the number of leucocytes as the lymph passes from the periphery to the larger vessels, and especially as the fluid passes through the glands, can be explained.

From the fact that leucocytes are developed before the lymphatic system makes its appearance, that they are found in lymph which has never passed through lymphatic glands, and from the observations just cited showing their spontaneous formation in an amorphous blastema, it is the inevitable con-

clusion that nearly, if not quite all, of the lymph-corpuscles are developed by genesis in the clear lymph-plasma, and that their development goes on as the fluid circulates toward the venous system. With regard to the influence of the lymphatic glands upon the generation of leucocytes, there is no evidence that the corpuscles which are developed in the course of the lymph through these organs are not here, as elsewhere, formed simply from the blastema; and it is not necessary to invoke any special formative action taking place in the peculiar structures of the glands.

The function of the lymph-corpuscles is obscure. They are discharged into the blood, of which they form a constant constituent. Aside from the hypothesis that they are concerned in the formation of the red blood-disks, no definite and reasonable theory of their physiological office has been proposed.

In addition to the ordinary leucocytes and a certain number of fatty granules, a few small clear globules or granules, about $\frac{1}{12000}$ of an inch in diameter, called sometimes globulins, are almost constantly present in the lymph. These are insoluble in ether and acetic acid, but are dissolved by ammonia. They are regarded by Robin as a variety of leucocytes and are described by him as free nuclei. They make their appearance in the blastema before the larger leucocytes are developed.

Origin and Function of the Lymph.—There can hardly be any doubt concerning the source of most of the liquid portions of the lymph, for they can be derived only from the blood. Although the exact relations between the smallest lymphatics and the blood-vessels have not been made out in all parts of the system, there is manifestly no anatomical reason why the water, mixed with albumen and fibrin and holding salts in solution, should not pass from the blood into the lymphatics; and this is rendered nearly certain if it can be demonstrated that the lymphatics partly or entirely

surround many of the blood-vessels; for under these circumstances, endosmotic and exosmotic currents would inevitably take place. We have seen, in comparing the composition of the lymph with that of the plasma of the blood, that the constituents of these fluids are nearly if not quite identical; the only variations being in their relative proportions. This is another strong argument in favor of the passage of most of the constituents of the blood into the lymph. The difference in the proportion of albumen is explained by the fact that this substance is but slightly exosmotic; and with regard to the proportion of fibrin, it is pretty well established that, in the blood, this principle is formed by a transformation of albumen. The same may occur in the lymph, particularly as the quantity of fibrin has been found to increase as the liquid passes from the periphery to the larger vessels.

One of the most important physiological facts in the chemical history of the lymph is the constant existence of a considerable portion of urea. This cannot be derived from the blood, for its proportion is greater in the lymph,[1] notwithstanding that this fluid is being constantly discharged into the blood-vessels. The urea which exists in the lymph is derived from the tissues; it is discharged then into the blood, and is constantly being removed from this fluid by the kidneys.

The positive facts upon which to base any precise ideas with regard to the general function of the lymph are not very numerous. From the composition of this fluid, its mode of circulation, and the fact that it is being constantly discharged into the blood, it would not seem to have an important function in the active processes of nutrition. The experiments of Collard de Martigny sustain this view, inasmuch as the quantity and the proportion of solid constituents of the lymph were rather increased than diminished in animals that had

[1] WURTZ, written communication, in LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 429, note.

been deprived of food and drink for several days; while it is well known that starvation always impoverishes the blood.[1] On the other hand, urea, one of the most important of the products of destructive metamorphosis of the tissues, is undoubtedly taken up by the lymph, and conveyed in this fluid to the blood. It remains now for future investigations to determine whether other excrementitious principles may not be taken up from the tissues in the same way—a question of great importance in its relations to the mechanism of excretion.

What is positively known with regard to the functions of the lymph may be summed up in a very few words: A great part of its constituents is evidently derived from the blood; and the relations of these principles (fibrin, albumen, and the ordinary inorganic salts) to nutrition are not understood. The same may be said of sugar, also a constant constituent of the lymph, the origin of which, even, is not known. Urea and, perhaps, other excrementitious matters are taken up from the tissues by the lymph, and are discharged into the blood, to be removed by the appropriate organs from the system.

While the blood is evidently the great nutritive fluid of the body, being constantly regenerated and purified by the absorption of nutritive matters, by respiration, and by the action of excreting organs, the lymph has an important function in removing from the tissues some, at least, of the products of physiological decay of the organism.

Chyle.

During the intervals of digestion, the intestinal lymphatics and the thoracic duct carry ordinary lymph; but as soon as absorption of alimentary matters begins, certain nutritive principles are taken up in quantity by these vessels, and their contents are now known as the chyle. But little remains to be said concerning this fluid, as we have consid-

[1] *Loc. cit.*

ered pretty fully the composition and properties of the lymph as well as the different principles taken up by the lacteal vessels which, with the lymph, form the chyle. Some general considerations, however, remain concerning the composition and properties of the chyle as a distinct fluid.

In the human subject and in carnivorous animals, the chyle taken from the lacteals near the intestine, where it is nearly pure, or from the thoracic duct, when it is mixed with lymph, is a white, opaque, milky fluid, of a slightly saline taste, and an odor which is said to resemble that of the semen. The odor is also said to be characteristic of the animal from which the fluid is taken; although this is not very marked, except on the addition of concentrated acid, the process employed by Barreul to develop the characteristic odor in the fluids from different animals.[1] Bouisson has found that the peculiar odor of the dog was thus developed in fresh chyle taken from the thoracic duct of this animal.[2]

The chyle taken from a fistula into the thoracic duct is frequently of a more or less rosy tint; and it has been a question whether this be due to a peculiar coloring matter or to the accidental presence of a few red blood-corpuscles. Colin, whose experiments in collecting chyle from living animals have been very numerous and successful, assumes that the red coloration is always due to blood-corpuscles coming from the subclavian vein; the valve at the orifice of the thoracic duct not being always sufficient to prevent regurgitation. He has never found blood in the fluid taken from the mesenteric vessels or the receptaculum chyli, and he states, furthermore, that the chyle from these vessels never becomes colored under the influence of the air or of oxygen.[3]

[1] See vol. i., p. 67.

[2] BOUISSON, *Études sur le Chyle.—Gazette Médicale de Paris*, 1844, tome xii., p. 412.

[3] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris 1856, tome ii., p. 7.

Dalton and others have noted the same fact, and have observed that the fluid which is first discharged after a tube is fixed in the thoracic duct is perfectly white, the rosy tint gradually appearing as the chyle flows from the fistula.[1] These views with regard to the coloration of the chyle after its discharge from the vessels are stated positively, as the result of numerous experiments; and there is every reason for supposing that they are correct, notwithstanding that Longet and some others have assumed that the chyle becomes tinged with red as the result of a transformation of a coloring matter peculiar to this fluid, "a matter with regard to the origin and nature of which we are not yet certain."[2]

The reaction of the chyle is either alkaline or neutral.[3] Dalton noted an alkaline reaction in the chyle of the goat and of the dog;[4] and a specimen of chyle taken from a criminal immediately after execution, and examined by Rees, was neutral.[5] Leuret and Lassaigne obtained the fluid from the receptaculum chyli in a man that had died of cerebral inflammation, and found its reaction to be alkaline.[6]

The specific gravity of the chyle is always less than that of the blood; but it is very variable, and depends upon the quality of the food and particularly upon the quantity of liquids ingested. Lassaigne found the specific gravity of a specimen of pure chyle taken from the mesenteric lacteals of

[1] DALTON, *Lectures on the Physiology of the Circulation.—American Medical Monthly and New York Review*, December, 1860, p. 409.

[2] LONGET, *Traité de Physiologie*, Paris, 1861, tome i., p. 423.

[3] Tiedemann and Gmelin found the fluid collected from the thoracic duct of a dog, four hours after eating, to be alkaline. (TIEDEMANN ET GMELIN, *Recherches sur la Route que prennent diverses Substances pour passer de l'Estomac et du Canal Intestinal dans le Sang*, etc., Paris, 1821, p. 4.)

[4] *Loc. cit.*

[5] REES, *On the Chemical Analysis of the Contents of the Thoracic Duct in the Human Subject.—Philosophical Transactions*, London, 1842, p. 8.

[6] LEURET ET LASSAIGNE, *Recherches Physiologiques et Chimiques pour servir à l'Histoire de la Digestion*, Paris, 1825, p. 165.

a bull to be 1,013,[1] and the specific gravity of the specimen of human chyle examined by Rees was 1,024.[2]

The differences in the appearance of the chyle in different animals depend chiefly upon the diet. Colin found it excessively milky in the carnivora, especially after fats had been taken in quantity; while in dogs that were nourished with articles containing but little fat, its appearance was hardly lactescent.[3] Tiedemann and Gmelin found the chyle almost transparent in herbivora fed with hay or straw. They also observed the fact that the chyle was nearly transparent in dogs fed with liquid albumen, fibrin, gelatine, starch, and gluten; while it was white in the same animals fed with milk, meat, bones, etc.[4]

It is impossible to give even an approximative estimate of the entire quantity of pure chyle taken up by the lacteal vessels. When it finds its way into the thoracic duct, it is mingled immediately with all the lymph from the lower extremities; and the immense quantities of fluid which have been collected from this vessel by Colin and others,[5] give no idea of the quantity of chyle absorbed from the intestinal canal. We cannot, therefore, attempt even to give an approximate estimate of absolute quantity of chyle; but it is evident that this is variable, depending upon the nature of the food and the quantity of liquids ingested.

Like the lymph, the chyle, when removed from the vessels, speedily undergoes coagulation. Different specimens of the fluid vary very much as regards the rapidity with which coagulation takes place. The contents of the thoracic duct taken from the inferior animals generally coagulates in a few minutes. The first portion of the fluid collected from

[1] Colin. *op. cit.*, tome ii., p. 7.

[2] *Loc. cit.*

[3] *Op. cit.*, p. 8.

[4] Tiedemann et Gmelin, *Recherches Expérimentales Physiologiques et Chimiques sur la Digestion*, Paris, 1827, première partie, p. 176 *et seq.*, and p. 308.

[5] See page 509.

the human subject by Dr. Rees (the chyle was collected in this case in two portions) coagulated in an hour.[1] Received into an ordinary glass vessel, the chyle generally separates more or less completely after coagulation into clot and serum, the density and size of the clot indicating the proportion of fibrin. The serum which thus separates is quite variable in quantity, and is never clear. Its milkiness does not depend entirely upon the presence of particles of emulsified fat, and it is not rendered transparent by ether; it contains, in addition to these particles, numerous leucocytes and organic granules.

Numerous observations have been made with reference to the influence of different kinds of food upon the chyle; but these have not been followed by any definite results that can be applied to the human subject. It is usual to find the chyle fluid in the lacteals and the thoracic duct for many hours after death; but it soon coagulates upon exposure to the air. Although the entire lacteal system is sometimes found, in the human subject and in the inferior animals, filled with perfectly opaque coagulated chyle,[2] the fluid does not often coagulate in the vessels.

Composition of the Chyle.—Analyses of the milky fluid taken from the thoracic duct during full digestion by no means represent the composition of pure chyle; and it is only by collecting the fluid from the mesenteric lacteals, that it can be obtained without a very large admixture of lymph. In the human subject, it is rare even to have an opportunity of taking the fluid from the thoracic duct in cases of sudden death during digestion; and in most of the inferior animals which have been operated upon, it is difficult to obtain fluid from the small lacteals in quantity sufficient for accurate

[1] Rees, *On the Chemical Analysis of the Contents of the Thoracic Duct in the Human Subject.—Philosophical Transactions*, London, 1842, p. 82.

[2] Cruikshank, *The Anatomy of the Absorbing Vessels of the Human Body*, London, 1790, p. 101.

analysis. In operating upon the ox, however, Colin has succeeded in collecting pure chyle in considerable quantity. In this animal, the lacteals are not numerous, but are of considerable size, and unite into a large trunk which follows the course of the mesenteric artery and vein. On introducing, in the living animal, a tube into this trunk or into one of its large tributaries, a considerable quantity of fluid may be collected in a very few minutes.

The chyle of the ox, collected in this way by Colin, was examined by Lassaigne, but unfortunately no complete analysis was made. The fluid contained 1·9 parts per 1,000 of dried fibrin, which was double the quantity found in the fluid from the thoracic duct of the same ruminant. The serum contained 952·1 parts of water and 47·9 parts of solid matters—albumen and salts.[1] Although the analysis of this fluid was not completed, it evidently contained all the organic and inorganic principles which exist in pure lymph and in the contents of the thoracic duct. Remembering, then, that even during the period of greatest activity in the absorption of alimentary matters, the contents of the thoracic duct consist largely of lymph, we must take the analyses of this mixed fluid as our only data for forming an approximative estimate of the proportions of the various constituents of the chyle. It must be borne in mind, also, that the composition of the chyle is constantly varying with the diet. As we have already shown in treating of absorption, many of the alimentary principles may be actually recognized in the fluid obtained from the lacteals during digestion and absorption.[2]

The most complete analysis of chyle from the human subject is given by Dr. Rees.[3] The fluid was taken from the thoracic duct of a vigorous man, a little more than an hour

[1] Colin, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 7.

[2] See page 445 *et seq.*

[3] Rees, *On the Chemical Analysis of the Contents of the Thoracic Duct in the Human Subject.—Philosophical Transactions*, London, 1842, p. 81 *et seq.*

after his execution by hanging. The subject was apparently in perfect health up to the moment of his death. The evening before, he ate two ounces of bread and four ounces of meat. At seven o'clock A. M., precisely one hour before death, he took two cups of tea and a piece of toast; and he drank a glass of wine just before mounting the scaffold. When the dissection was made, the body was yet warm, although the weather was quite cold. The thoracic duct was rapidly exposed and divided, and about six fluidrachms of milky chyle were collected. The fluid was neutral, and had a specific gravity of 1,024. The following was its proximate composition:

Composition of Human Chyle from the Thoracic Duct.

Water	904·8
Albumen, with traces of fibrinous matter	70·8
Aqueous extractive	5·6
Alcoholic extractive, or osmazome	5·2
Alkaline chloride, carbonate, and sulphate, with traces of alkaline phosphates and oxides of iron	4·4
Fatty matters	9·2
	1,000·0

Of the constituents of the chyle not given in the ordinary analyses, the most important are the urea, which is derived exclusively from the lymph, and sugar, coming from the saccharine and amylaceous articles of food during the digestion of these principles.

The difference in chemical composition between the unmixed lymph and the chyle is very well illustrated in a comparative examination of these two fluids taken from a donkey. The fluids were collected by Mr. Lane, the chyle being taken from the lacteals before reaching the thoracic duct. The animal was killed seven hours after a full meal of oats and beans. The following analyses of the fluids was made by Dr. Rees:[1]

[1] REES, *On Chyle and Lymph.—London Medical Gazette*, 1841, vol. xxvii., p. 547; and LANE, *Lymphatic and Lacteal System.—Cyclopædia of Anatomy and Physiology*, London, 1839–1847, vol. iii., p. 223.

Composition of Chyle and Lymph before reaching the Thoracic Duct.

	Chyle.	Lymph.
Water	902·37	965·36
Albuminous matter	35·16	12·00
Fibrinous matter	3·70	1·20
Animal extractive matter soluble in water and alcohol	3·32	2·40
Animal extractive matter soluble in water only	12·33	13·19
Fatty matter	36·01	a trace
Salts, { Alkaline chloride, sulphate and carbonate, with traces of alkaline phosphate, oxide of iron, }	7·11	5·85
	1,000·00	1,000·00

The above analysis shows a very marked difference in the proportion of solid constituents in these two fluids. The chyle contains about the same proportion of albumen and fibrin as the lymph, and a much larger proportion of salts. The proportion of fatty matters in the chyle is very great, while in the lymph there exists only a trace.[1]

The individual constituents of the chyle given in the above tables do not demand any further consideration than they have already received under the head of lymph. The albuminoid matters are in part derived from the food, and in part from the blood, through the admixture of the chyle with lymph. The fatty matters are derived in greatest part from the food. As far as has been ascertained by analyses of the chyle for salts, this fluid has been found to contain essentially the same inorganic constituents as the plasma of the blood. All of these principles are rapidly poured into the blood, where they assist in supplying the material which is being constantly consumed in the process of nutrition.

[1] The proportion of fat given in this analysis of the chyle is even greater than the proportion given by Nasse in an analysis of the chyle of the cat, which is very commonly quoted as a specimen of chyle extraordinarily rich in fatty matters. The probable explanation of the large proportion of fat found by Rees is that the fluid was taken from the lacteals, and was not mixed with lymph in the thoracic duct. The proportion of fat in the analysis made by Nasse was 32·7 parts per 1,000. (Nasse, *Chylus*—Wagner's *Handwörterbuch der Physiologie*, Braunschweig, 1842, Bd. i., S. 235.)

The presence of sugar in the chyle was first mentioned by Brande, who described it, however, rather indefinitely.[1] Glucose was distinctly recognized in the chyle by Trommer,[2] and its existence in many of the higher orders of animals has since been fully established by Colin.[3]

Microscopical Characters of the Chyle.—The milky appearance of the chyle as contrasted with the lymph is due to the presence of an immense number of excessively minute fatty granules. The liquid becomes much less opaque when treated with ether, which dissolves many of the fatty particles. In fact, the chyle of the thoracic duct is nothing more than lymph to which an emulsion of fat in a liquid containing fibrin, albumen, and salts is temporarily added during the process of intestinal absorption. The quantity of fatty granules in the chyle varies considerably with the diet, and generally diminishes progressively from the smaller to the larger vessels, on account of the constant admixture of lymph. The size of the granules is pretty uniformly from $\frac{1}{25000}$ to $\frac{1}{12500}$ of an inch.[4] They are much smaller and more uniform in size in the lacteals than in the cavity of the intestine. Their constitution is not constant; and they are composed of the different varieties of fat which are taken as food, mixed together in variable proportions. This fact was well illustrated in the experiments of Bouchardat and Sandras, who even detected certain peculiar kinds of fat which had been fed to dogs, in the contents of the lacteals and the thoracic duct.[5]

[1] BRANDE, *Chemical Researches on the Blood and some other Animal Fluids.—Philosophical Transactions*, London, 1812, p. 96.

[2] TROMMER, *Unterscheidung von Gummi, Dextrin, Traubenzucker, und Rohrzucker.—Annalen der Chemie und Pharmacie*, Heidelberg, 1841, Bd. xxxix., S. 360.

[3] COLIN, *De l'Origine du Sucre contenu dans le Chyle.—Journal de la Physiologie*, Paris, 1858, tome i., p. 539 *et seq.*

[4] ROBIN, in NYSTEN'S *Dictionnaire de Médecine*, Paris, 1865, article *Chyle.*

[5] BOUCHARDAT ET SANDRAS, *Recherches sur la Digestion et l'Assimilation des Corps gras.—Annuaire de Thérapeutique*, Paris, 1845, p. 242 *et seq.*

The ordinary corpuscular elements of the lymph—leucocytes and globulins—are also found in variable quantity in the chyle. These have already been fully considered.

Movements of the Lymph and the Chyle.

Compared with the current of blood, the movements of the lymph and chyle are feeble and irregular; and the character of these movements is such that they are evidently due to a variety of causes. As regards those elements which are derived directly from the blood, the lymph may be said to undergo a true circulation; inasmuch as there is a constant transudation at the peripheral portion of the vascular system of fluids which are returned to the circulating blood by the communications of the lymphatic system with the great veins. But we have seen that the lymph is not derived entirely from the blood, a considerable portion resulting from interstitial absorption in the general lymphatic system, and from the absorption of certain nutritive matters by the chyliferous vessels. These are, physiologically, the most important constituents of the lymph and chyle; and they are taken up simply to be carried to the blood, and do not pass again from the general vascular system into the lymphatics.

As far as the mode of origin of the lymph and chyle has any bearing upon the movements of these fluids in the lymphatic vessels, there is no difference between the imbibition of new materials from the tissues or from the intestinal canal, and the transudation of the liquid portions of the blood; for the mechanism of the passage of liquids from the blood-vessels is such that the motive power of the blood cannot be felt. An illustration of this is in the mechanism of the transudation of the liquid portions of the secretions. The force with which fluids are discharged into the ducts of the glands is enormous, and is independent of the action of the heart; being due entirely to the force of transudation and secretion. This is combined with the force of imbibition,

and with it forms one of the important agents in the movements of the lymph and chyle.

These movements are studied with great difficulty. One of the first peculiarities to be observed is, that under normal conditions, the vessels are seldom distended; and the quantity of fluid which they contain is subject to considerable variation. As far as the flow in the vessels of medium size is concerned, the movement is probably continuous, subject only to certain momentary obstructions or accelerations from various causes. But in the large vessels situated near the thorax, and in those within the chest, the movements are in a marked degree remittent, or may even be intermittent. All experimenters who have observed the flow of lymph or chyle from a fistula into the thoracic duct have noted a constant acceleration with each act of expiration; and an impulse synchronous with the pulsations of the heart has been frequently observed.

The fact that the lymphatic system is never distended, and the existence of the numerous valves by which different portions may become isolated, render it impossible to estimate the general pressure of fluid in these vessels. This is undoubtedly subject to great variations in the same vessels at different times, and in different parts of the lymphatic system. It is well known, for example, that the amount of distension of the thoracic duct is exceedingly variable, its capacity not infrequently being many times increased during active absorption. At the same time it is difficult to attach a manometer to any part of the lymphatic system without seriously obstructing the circulation, and consequently exaggerating the normal pressure. But the force with which liquids penetrate these vessels is very great. This is illustrated by the experiment of ligating the thoracic duct; for after this operation, unless communicating vessels exist by which the fluids can be discharged into the venous system, their accumulation is frequently sufficient to rupture the vessel.

The general rapidity of the current in the lymphatic vessels has never been accurately estimated. As a natural consequence of the variations in the distention of these vessels, the rapidity of the circulation must be subject to constant modifications. Béclard, making his calculation from the experiments of Colin, who noted the quantity of fluid discharged in a given time from fistulous openings into the thoracic duct, estimates that the rapidity of the flow in this vessel is about one inch per second.[1] This estimate, however, can be only approximative; and it is evident that the flow must be much less rapid in the vessels near the periphery than in the large trunks, as the liquid moves in a space which becomes rapidly contracted as it approaches the openings into the venous system.

Causes of the Movements of the Lymph and Chyle.

Various influences combine to produce the movements of fluids in the lymphatic system, some being constant in their operation, and others intermittent or occasional. These will be considered, as nearly as possible, in the order of their relative importance.

Influence of the Forces of Endosmosis and Transudation (*vis a tergo*).—The forces of endosmosis and transudation are undoubtedly the main causes of the lymphatic circulation, more or less modified, however, by influences which may accelerate or retard the current; but this action is capable in itself of producing the regular movement of the lymph and chyle. It is a force which is in constant activity, as is seen in cases of ligation of the thoracic duct, an operation which must finally abolish all other forces which aid in producing the lymphatic circulation. When the receptaculum chyli is ruptured, as a consequence of obstruction of the thoracic duct, the vessel gives way as the result of the constant endosmotic

[1] Béclard, *Traité Élémentaire de Physiologie Humaine*, Paris, 1859, p. 180.

action, in the same way that the exposed membranes of an egg may be ruptured by endosmosis, when immersed in water.

We have already alluded to the influence of transudation from the blood-vessels, and compared it to the force with which the secretions are discharged into the ducts of the glands; and in placing this, with the force of endosmosis, at the head of the list of the agents which effect the lymphatic circulation, its importance is not over-estimated. This conclusion can hardly be avoided, when we consider the anatomy of the lymphatic system. The situations in which the endosmotic force originates are at the periphery, where the single homogeneous wall of the plexus is excessively thin, and the extent of absorbing surface is enormous. If liquids can penetrate with such rapidity and force through the walls of the blood-vessels, where their entrance is opposed by the pressure of the fluids already in their interior, they certainly must pass without difficulty through the walls of the lymphatics, where there is no lateral pressure to oppose their entrance, except that produced by the weight of the column of liquid. This pressure is readily overcome; and the numerous valves in the lymphatic system effectually prevent any backward current. Every particle of liquid that passes into the lymphatics by endosmosis or by transudation, produces movement by displacing an equal bulk of liquid contained in the vessel. We observe with the microscope the rapid filling and rupture of microscopic cells when immersed in water; and the rough experiments by which the operation of endosmosis is ordinarily illustrated, in which the extent of endosmotic surface is infinitely small compared with the lymphatic system, exhibit a current of considerable force and rapidity. When we remember that the infinitely numerous lymphatic radicles are bathed in fluids, which undoubtedly pass into their interior with great facility, and compare the probable extent of this endosmotic surface with the diameter of the thoracic duct, we can hardly be surprised that this force should be ca-

pable of producing a movement in the great trunk at the rate of an inch per second. The great elasticity of the vessels and the fact that they are never completely filled allow of considerable distension of isolated portions of the lymphatic system, when there is any obstruction to the current that is not readily overcome. In this way we account for the variations in the flow of the lymph and chyle which are of such constant occurrence.

Influence of the Contractile Walls of the Vessels.—In treating of the anatomy of the lymphatic system, it has already been observed that the large vessels and those of medium size are provided with unstriped muscular fibres, and are endowed with contractility.[1] This fact has been demonstrated by physiological as well as anatomical investigations. Béclard states that he has often produced contractions of the thoracic duct by the application of the two poles of an inductive apparatus.[2] It is not uncommon to see the lacteals become reduced in size to a mere thread, even while under observation. Although experiments have generally failed to demonstrate any regular rhythmical contractions in the lymphatic system,[3] it is probable that the vessels contract upon their contents, when they are unusually distended, and thus assist the circulation, the action of the valves opposing a regurgitating current. This action, however, cannot have any considerable and regular influence upon the general current.[4]

[1] See page 437.

[2] BÉCLARD, *Traité Élémentaire de Physiologie Humaine*, Paris, 1859, p. 177.

[3] COLIN is quoted as having observed rhythmical contractions in the mesenteric lymphatics in the ox; but as far as we know, his experiments have not been published. (LABÉDA, *Système Lymphatique, Cours du Chyle et de la Lymphe*, Paris, 1866, p. 63.)

[4] In some of the lower vertebrate animals, in which the lymphatic vessels have no valves, there exist several contractile dilatations, or hearts, which are provided with valves, and which pulsate regularly. These were discovered by Müller, in 1832, in frogs, toads, and lizards. (MÜLLER, *Manuel de Physiologie*,

Influence of Pressure from Surrounding Parts.—Contractions of the ordinary voluntary muscles, compression of the abdominal organs by contraction of the abdominal muscles, peristaltic movements of the intestines, and pulsations of large arteries situated against the lymphatic trunks, particularly the thoracic aorta, are all capable of increasing the rapidity of the circulation of the lymph and chyle.

The contractions of voluntary muscles assist the lymphatic circulation in precisely the same way in which they influence the flow of blood in the venous system; and we have nothing to add regarding this action to what has already been said on this subject in connection with the venous circulation.[1] The fact that muscular movements actually accelerate the flow of lymph has been conclusively demonstrated by Colin, who found that when a tube was introduced into any of the lymphatic vessels of the neck, in the horse or the large ruminants, the discharge of fluid in a given time was increased one-quarter, one-third, and even one-half, during movements of mastication.[2]

Increase in the flow of chyle in the thoracic duct, as the result of compression of the abdominal organs, or by kneading the abdomen with the hands, was observed by Magendie,[3] and the fact has been confirmed in all recent experiments on this subject. The same effect, though probably less in degree, is produced by the peristaltic contractions of the intestines.

When a tube is introduced into the upper part of the thoracic duct, it is frequently the case that the fluid is discharged more forcibly with each pulsation of the heart.

Paris, 1851, tome i., p. 208; and POGGENDORFF'S *Annalen der Physick und Chemie*, Leipzig, 1832, Bd. xxv., S. 517.)

[1] See vol. i., p. 317 *et seq.*; and page 325 *et seq.*, for the function of the valves of the veins.

[2] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 89.

[3] MAGENDIE, *Précis Élémentaire de Physiologie*, Paris, 1836, tome ii., p. 183.

This was frequently observed by Dalton in his experiments on the thoracic duct, and he describes the jets as being "like blood coming from a small artery when the circulation is somewhat impeded."[1] This impulse is due to compression of the thoracic duct as it passes under the arch of the aorta. Its influence upon the general current of the lymph and chyle is probably insignificant, but the fact attracted the attention of Haller, who attached to it a great deal more importance than it is now believed to possess.[2]

Influence of the Movements of Respiration.—While the *vis a tergo* must be regarded as by far the most important agent in the production of the lymphatic circulation, the movements of fluids in the thoracic duct receive constant and important aid from the respiratory acts. This fact has long been recognized; and in the works of Haller will be found a full discussion of the influence of the diaphragm and the movements of the thorax upon the circulation of chyle.[3] The observations of Colin on this subject are most valuable, as he was the first to successfully establish a fistula into the thoracic duct in large animals. He always found a marked remittency in the flow of chyle from a fistula into the thoracic duct, which was absolutely synchronous with the movements of respiration. With each act of expiration, the fluid was forcibly ejected, and with inspiration, the flow was very much diminished or even arrested. These impulses became much more marked when respiration was interfered with and the efforts became violent. The intermittency of the current was sometimes so decided, that the pulsations were repeated in a long elastic tube attached to the canula for the

[1] DALTON, *Lectures on the Physiology of the Circulation.—American Medical Monthly and New York Review*, December, 1860, p. 416.

[2] HALLER, *Elementa Physiologiæ Corporis Humani*, Bernæ, 1765, tomus vii., p. 237.

[3] Ibid.

purpose of collecting the fluid.[1] These observations were confirmed by Dalton, who noted the interesting fact, that in animals poisoned with woorara, in which artificial respiration was continued by insufflation, the phenomena were reversed; the abundant discharge then took place with insufflation, when the parts contained in the thorax were compressed by the distended lungs, and in the intervals, the flow became scanty or ceased.[2]

The amount of influence exerted by the respiratory movements upon the flow of the lymph and chyle can be best appreciated by examining carefully the mechanism of its operation.

With each act of inspiration, all the liquids, as well as the air, are drawn toward the cavity of the thorax. In this way, the thoracic duct is dilated and then becomes most distended with fluid. At the same time, the flow of lymph from the right lymphatic duct into the right subclavian vein is increased. After the thoracic duct has been thus dilated in inspiration, at the moment of expiration, in common with all the other parts contained within the thorax, it undergoes compression; the valves prevent the reflux of its contents, and, as a necessary consequence, the fluid is then discharged with increased force into the left subclavian vein. It can be readily understood how the act of inspiration, while it has a tendency to fill the thoracic duct from below, opposes the discharge of fluid from a fistula.

From all these considerations, it is evident that, although there are many circumstances capable of modifying the currents in the lymphatic system, the regular flow of the lymph and chyle depends chiefly upon the *vis a tergo;* but the vessels themselves sometimes undergo contraction, and they are subject to occasional compression from surrounding parts, which, from the existence of numerous valves in

[1] COLIN, *Traité de Physiologie Comparée des Animaux Domestiques*, Paris, 1856, tome ii., p. 90.

[2] DALTON, *op. cit.*, p. 416.

the vessels, must favor the current toward the venous system. The alternate dilatation and compression of the thoracic duct with the acts of respiration is likewise an aid to the circulation, and is more efficient than any other force, except the *vis a tergo*. The action of the valves is precisely the same in the lymphatic as in the venous system.

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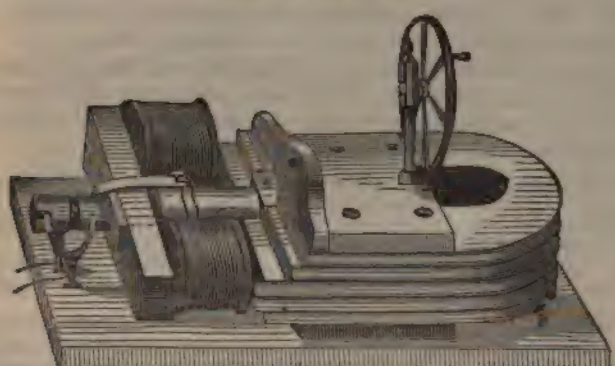

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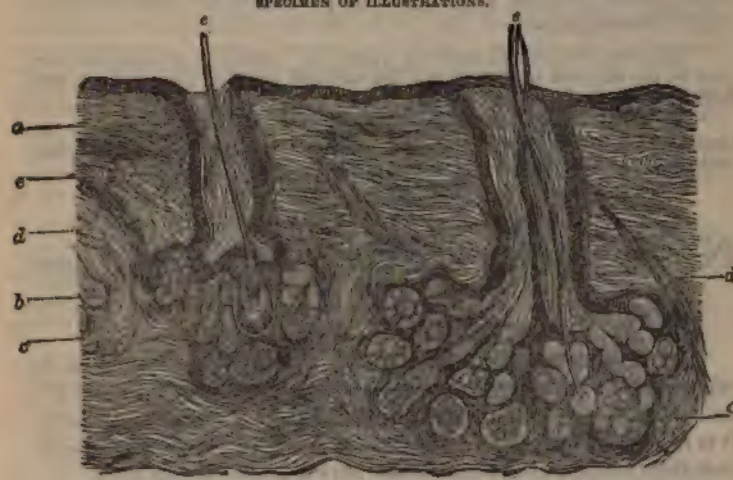

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